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CORRECTIONS

Volume 62, April 1934, page 131, second column, the second sentence should read, "The greatest difference was 2.1°, in 1918, and the least, 1.2°, in 1926, 1932, and 1933." In the same column, third paragraph, the third sentence should read, "July shows the greatest difference, and April the least, 1.4° and 0.7°, respectively. The greatest difference for any individual month was 2.1°, in September 1928, while, as indicated above, the least was for April 1927, 0.0°."

Volume 62, June 1934, page 186, the author's name is "Pagliuca". In the half-tone facing page 188, figure 3 is upside down.

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ON THE RELATION BETWEEN RAINFALL AND STREAM FLOW

By Richmond T. Zoch

[Weather Bureau, Washington, June 1934]

INTRODUCTION

In the act of Congress transferring the meteorological work of the Signal Office to the Weather Bureau of the Department of Agriculture, approved October 1, 1890, the duties of the service are thus summarized (1):

> The Chief of the Weather Bureau, under the direction of the Secretary of Agriculture, shall have charge of forecasting the weather; the issue of storm warnings; the display of weather and flood signals for the benefit of agriculture, commerce, and navigation; the gaging and reporting of rivers; the maintenance and operation of seacoast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation; the reporting of temperature and rainfall conditions for the cotton interests; the display of frost, cold wave, and other signals; the distribution of meteorological information in the interest of agriculture and commerce; and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.

To carry out the provision, "the display of * * * flood signals for the benefit of agriculture, commerce, and navigation; the gaging and reporting of rivers" the Weather Bureau has established some sixty-odd river district centers. These centers supervise the work of about 900 substations, and issue forecasts and warnings of river stages to the public.

It is conservative to state that $3,000,000 worth of property is saved annually as a result of the Weather Bureau's flood warnings.[1]

At the present time, empirical methods solely are used by the Weather Bureau in forecasting river stages and issuing flood warnings. In large rivers where the day-to-day changes are gradual these methods are very efficient, and it is doubtful whether any other methods based on theory, however elaborate, will add very much to them. As an example of the precision of the present methods, the following is quoted from Talman: "Thus in the flood of 1903 the exact time when the crest would reach New Orleans was correctly foretold 28 days in advance and the prediction of the height of the crest was only 5 inches in error." (2)

In small streams, however, where the height of the water surface may change several feet in a few hours the present empirical methods are not so efficient. Contrast the precision of the New Orleans forecast just mentioned with a forecast for a station on a small river made recently, when a stage exceeding any that had occurred there for 15 years was predicted when, as a matter of fact, the river rose only 1.3 feet, a bare one-fifth of the rise expected.[2]

The reason for the great accuracy in predictions for large streams is the fact that for them the forecasts need not be made until the crest has passed some upstream gage; and the further fact that when an upstream gage reaches a certain stage then a gage farther downstream will, at a so much later time, reach a corresponding stage, and this relation can be worked out quite closely. In the small streams, either there may be no gage farther upstream or, if there is one, the time of flood crest travel is so short that it is not feasible to wait for the upstream gage reading; in each case, therefore, flood forecasts must be based on the rainfall. In the large streams, about the only things that cause a flood forecaster to be appreciably in error are the breaking of a levee or dam, or some other similar engineering or flood-protection work, and the erratic movements of ice. In a small stream where the flood forecasts are based on rainfall, not only are there these items to contend with but also the dryness and other conditions of the soil on which the rain falls; possible unequal distribution of rainfall over the watershed; the presence of a snow cover, if any; the effect of evaporation and transpiration; and, of course, the basic factors, i. e., the depth and the rate of the rainfall.

Evidently, then, a study of the underlying principles of the relation between rainfall and consequent run-off and stream flow ought to improve the efficiency of the Weather Bureau's flood warnings in the smaller streams. Accordingly a series of articles, of which this is the first, has been prepared on this subject.

It is well to bear in mind the limitations of any system of flood forecasting. Near the headwaters of a stream, flood crests are reached very soon after the flood-producing rain stops. Indeed, by the time a rainfall observer in the upper portion of the drainage basin has telegraphed the rainfall to a river district center, and the center in turn has tabulated such reports from the several stations in a watershed, determined the forecast, and issued it to the public, the flood crest may already have passed. Thus any system of flood forecasting based upon rainfall, however exact, is of no practical use near the headwaters of streams. Again, for the large streams the simple empirical methods are to be preferred to any complex method based on theory, when the use of the latter effects only a very slight gain in the accuracy of the forecasts. Hence the theory developed in this series of articles

[1] An excellent description of the Weather Bureau's river and flood service is given in ch. X of "Meteorology" by W. I. Milham, New York, 1912.
Further explanations are contained in a pamphlet of the U. S. Department of Agriculture entitled "The Weather Bureau", Miscellaneous Publication No. 114.
These references despite the fact that in some ways they are not up to date, give a good summary of the river and flood service.

[2] It also is interesting to know that about 3 weeks later, rains not quite so heavy occurred above this station, and on account of the previous experience no flood warning was issued. However, the river reached a crest 0.5 foot over the flood stage and caused slight damage.
In another instance, on a different river, when the gage reading was 13 feet a forecast was issued for a crest stage between 20 and 21 feet; however, the river fell.

is practically applicable only to that reach of a river that is comparatively near the headwaters, but not too near.

Yet even for these portions of the rivers of the United States it is believed that it is possible to improve greatly the accuracy of the Weather Bureau's flood warnings, and thus bring about the saving of much property annually.

The articles in this series are in three groups. The first group deals with the development of the mathematical theory of the relation between rainfall, run-off, and stream flow. The second applies this theory to some of the rivers of the United States, and shows how it is possible to forecast floods accurately from rainfall. The third group shows how it is feasible to construct nomograms from which it is possible to read off resulting river stages from given initial conditions of rain, evaporation, and soil capacity. It might be well to point out here that the purpose of the articles in the third group is to develop a ready method of applying the theory; for the practical value of any theory would be vitiated if from 1 to 6 hours of tedious computation were required, after the rainfall observer's reports were received, before a flood warning could be issued.

There will be seven articles in the first group. This, the first, treats the simple case in which the drainage area is rectangular; evaporation and transpiration are neglected; the rate of rainfall, the velocity of the water in the stream, and the condition (dryness) of the soil are constant; and where no snow cover is present. The second article will deal with irregularly shaped drainage areas, the third with evaporation (transpiration is a special case of evaporation), the fourth with varying rates of rainfall, the fifth with varying conditions of the soil, the sixth with varying velocity of water in the stream, and finally in the seventh article, the last of the first group, various combinations of the above factors will be treated.[3]

Each article consists of two parts. The first part tells in words what is accomplished mathematically, by symbols, in the second part. Those readers who are interested in flood forecasting from rainfall, or in the relation between rainfall, run-off, and stream flow, but who do not care to follow the mathematical formulas, need not read the second part of any article. However, those who intend to follow the mathematics should also read the first part of each article. The two parts of some of the articles are subdivided into sections.

PART I

SECTION 1.—THE DISCHARGE FROM A SMALL AREA

When rain falls upon the ground, part of it soaks into (or remains upon) the soil, and part runs off. Consider now that part which runs off. The volume of water running off a unit area per unit of time at any given time is here termed the *rate of run-off*. The volume of water which runs off a unit area in a given interval of time is termed the *run-off*. The run-off is a volume per unit area; the rate of run-off is volume per unit area per unit time. Mathematically, the rate of run-off is the first derivative of the run-off with respect to time.

Unfortunately, in the existing literature on hydrology the term "run-off" is used in both the above senses. It is even more confusing since the term "run-off" is also used for the *volume of run-off* from a given area.

Next consider the rain falling upon the ground. The depth of rain water, as a horizontal sheet, which falls upon the ground in a given interval of time is termed the *rainfall*. The rainfall is a length; the Weather Bureau has always measured rainfall in inches, and in these papers that practice is followed. The depth of rain water falling upon the ground per unit of time at any given time is termed the *rate of rainfall*. The rate of rainfall is depth per unit of time, and is here expressed in inches per hour. Mathematically, the rate of rainfall is the first derivative of the rainfall with respect to time. The volume of rain water which falls upon a given area in a given interval of time is termed the *volume of rainfall*. The volume of rainfall is length times area (i. e., volume), and is here expressed in mile-inches in preference to acre-feet—the latter term being common in literature on hydrology. The mile-inch is here defined as the volume of water which will cover 1 square mile to the depth of 1 inch. The mile-inch is the most convenient unit to use for the volume of rainfall since drainage areas are most commonly expressed in square miles and the rainfall in inches.

Consider further that part which runs off. The run-off, as above defined, will be expressed in inches; this is in keeping with present usage in hydrology. The rate of run-off is expressed in inches per hour rather than in cubic feet per second per square mile. It is necessary to introduce two more terms when dealing with areas other than a unit area. The volume of water which runs off a given area in a given interval of time will be termed the *volume of run-off*. The volume of run-off is length times area, and (as in the case of the volume of rainfall) will be expressed in mile-inches. The volume of water running off a given area per unit of time at any given time will be termed the *volume of rate of run-off*. The volume of rate of run-off is length per unit of time times area, and will be expressed in mile-inches per hour in preference to cubic feet per second.

Consider now the water flowing in a stream. The quantity of water flowing past a given cross section of a stream per unit of time at a given time is termed the *discharge*. The quantity of water which flows past a given cross section of a stream in a given interval of time is termed the *volume of discharge*. The volume of discharge is volume; the discharge is volume per unit time. Mathematically, the discharge is the first derivative of the volume of discharge with respect to time. Discharge is expressed in the same units as the volume of rate of run-off, i. e., in mile-inches per hour. Volume of discharge is expressed in the same units as the volume of run-off, i. e., in mile-inches.

As in the case of the term "run-off", it is unfortunate that the term "discharge" has been used in both of the above senses in the literature on hydrology.

If we confine our attention to a small parcel of ground which is drained by a single outlet, we may neglect the time required for the water that runs off to flow from where the rain falls to the outlet; in this case the *volume of run-off* from the whole small parcel of ground is synonymous with the *volume of discharge* at the outlet during any interval of time; and also the *volume of rate of run-off* is synonymous with the *discharge*.

In section 1 of part II, two equations are developed from fundamental principles. Equation (1) expresses the volume of rate of run-off as a function of time while the rain is falling. Equation (2) expresses the volume of rate of run-off as a function of time after the rain stops. In equation (2) evaporation is ignored. Evaporation will be considered in a later article.

In section 1, part II, there is also a discussion of a certain constant of proportionality introduced in the development of equations (1) and (2).

[3] Unforeseen circumstances may necessitate changing the order of some of these articles.

It is important to distinguish carefully between the terms *discharge* and *volume of rate of run-off*. When we are dealing with the volume of rate of run-off then equations (1) and (2) are true regardless of the *size and shape* of the drainage area. When we are dealing with discharge, equations (1) and (2) will be true only when the drainage area is small. The distinction between discharge and volume of rate of run-off will be more clearly brought out in section 2.

For convenience, and as a summary, all of the terms defined in this section, together with the units in which they are expressed, are here tabulated.

Term	Symbol	Units in which expressed
Rate of run-off	z	Inches per hour.
Run-off	$\int_0^t z\,dt$	Inches.
Rainfall	R	Do.
Rate of rainfall	$\frac{dR}{dt}=r$	Inches per hour.
Volume of rainfall	$AR=\int_0^t Ar\,dt$	Mile-inches.
Volume of run-off	$A\int_0^t z\,dt$	Do.
Volume of rate of run-off	$Az=Z$	Mile-inches per hour.
Discharge	y	Do.
Volume of discharge	$\int_0^t y\,dt$	Mile-inches.

SECTION 2.—THE DISCHARGE FROM A RECTANGLE

The primary concern of these articles is to develop a scheme whereby the height of flood crests can be predicted from the rainfall during a storm and attendant modifying factors. The height of a flood crest is a quantity which is easily observed and measured. Now, the discharge of a stream at a given cross-section may be regarded as a function of two things—one, the gage height of the stream at this cross-section; the other, whether the stream is rising or falling, i. e., the rate of change in that height, for it is well known that the discharge of a stream for a given gage height is greater when the stream is rising than for the same gage height when the stream is falling. Therefore, at the time of a crest the discharge of a stream at a given cross-section is a function of the height only, for then the stream is neither rising nor falling, i. e., the rate of change in height is zero. We may also say that the flood crest height is a function of the maximum discharge. Thus if the maximum discharge could be predicted, then the flood crest height could be predicted, and vice versa; assuming, of course, that the functional relation between the maximum discharge and flood crest height is known.

The functional relation between maximum discharge and flood crest height will be taken up in the second group of papers in the series; for the present we shall be concerned with establishing the relation between the rainfall during a storm (and other attendant factors) and the maximum discharge.

The relation between the rainfall during a storm (and accompanying factors) and the consequent volume of rate of run-off is readily obtained, as the reader may observe later; but the relation between the rainfall and the discharge, in general, is exceedingly involved. Therefore, in order to make this relation at all tractable, simple assumptions are made. What actually happens in Nature is replaced, at first, by a reasonable, workable ideal. Thus in section 2 of part II the relation between rainfall and discharge is worked out on the assumptions that: (1) there is no evaporation, (2) the rainfall and also the rate of rainfall are constant for a given storm, (3) the drainage area is rectangular, (4) the velocity of the water in the stream is constant, (5) the condition of the soil in the drainage area is uniform, (6) there is no snow cover on the soil. Now such ideal conditions never occur in Nature; and in later papers the relation between rainfall and discharge will be obtained when the above restrictions are removed one by one. Here again, in order to make this problem tractable it is necessary to confine the treatment to relatively simple cases as the assumptions enumerated above are removed.

For a large drainage area, the time required for the water that runs off to flow from where the rain falls to the outlet is appreciable, and, naturally, varies with the distance from the outlet. For this reason the volume of run-off and the volume of discharge during a given interval of time are by no means synonymous. Neither is the volume of rate of run-off, in general, identical with the discharge. However, after a prolonged period without any rain over a given drainage area, or in other words, when a steady state has been reached, the rate of run-off becomes constant (that is to say, the rate of run-off changes but little with respect to time) and therefore the volume of rate of run-off becomes equal to the discharge. Moreover, if the interval of time is taken to begin at one steady state and end at another steady state, then the volume of run-off equals the volume of discharge.[4]

In section 2, part II, equation (7) gives the time of the flood crest (maximum discharge) in terms of the duration of the rain and other constants. Equation (8) gives the maximum discharge in terms of the rate of rainfall, the time of maximum discharge, the duration of the rain, and other constants.

PART II

FOREWORD

In preparing a paper which contains tedious mathematical developments, the writer is confronted with the question of how fully these developments should be given: If each is given in full, the cost of publication is unduly increased, and moreover the reader is likely to receive the false impression that the paper is very complicated. On the other hand if the developments are condensed too much, by the omission of intermediate steps or by inadequate explanations, the reader may be unable to follow the paper even though he has a good grasp of the mathematics used. In view of the fact that the prediction of flood crests is a very practical problem, it has been deemed advisable to go to much pains in order to make the mathematical developments clear. Accordingly the following procedure is used in this paper: In deriving equation (1), the symbolic expression for each intermediate step is given, as well as a verbal explanation. For the remaining equations, the symbols for the more simple steps are omitted. It is believed that all readers who can follow the development of equation (1) will be able to supply all the omitted steps in the rest of the paper from the explanations given.

The present paper involves no mathematics beyond elementary calculus.

SECTION 1

Equations are here developed for the relation between rainfall and the rate of run-off, on the assumption that the rate of run-off at any given time is proportional to the

[4] It is worth noting that for an interval beginning with a steady state but ending with an unsteady state, the volume of run-off equals the sum of the volume of discharge and the volume of water in the stream at the time that the interval ends.

rainfall remaining with the soil at that time. It is believed that this assumption, which is the basis for all the equations developed in this series of papers, is a very close approximation to, if not precisely, what occurs in Nature.

Let t be the time, and let $t=0$ when the rain begins; let R be the rainfall that has fallen up to time t, and put $dR/dt=r$. Consider now the case when r is constant.

Let A be the area of a parcel of ground. Now the volume of rainfall remaining with A at any time, measured from the beginning of the rain, is a function of that time; that is to say, the volume of rainfall which has fallen up to time t, less the volume of water which to then has run off, is the volume remaining and is a function of the time t; in symbols:

$$\int_0^t Ardt-\int_0^t Zdt=\phi(t),$$

where Z is the volume of rate of run-off, and $\phi(t)$ is the volume remaining.

The fundamental assumption is: $cZ=\phi(t)$, where c is an unknown constant of proportionality. Therefore we can write $cZ=\int_0^t Ardt-\int_0^t Zdt$, and by differentiation we get $cdZ=Ardt-Zdt$, then solving for dt, $\frac{cdZ}{Ar-Z}=dt$, whence by integration $t=-c \log (Ar-Z) -c \log K$; dividing by $-c$ and combining terms, we have $-\frac{t}{c}=\log K(Ar-Z)$. It follows from the definition of a logarithm that this last equation can be written

$$e^{-\frac{t}{c}}=K(Ar-Z),$$

where e is the base of natural logarithms.

To evaluate the constant of integration K, set $Z=0$ when $t=0$; i. e., we assume that when the rain begins there is no water flowing off. Then

$1=KAr$ or $K=\frac{1}{Ar}$, and on substituting this value of K we have

$$e^{-\frac{t}{c}}=1-\frac{Z}{Ar};$$

hence, on solving for Z,

$$Z=Ar\left(1-e^{-\frac{t}{c}}\right). \qquad (1)$$

As $t\rightarrow\infty$, then $Z\rightarrow Ar$, which means that if the rain be prolonged without limit a state will be reached when there is just as much water flowing off the area as there is rain falling upon it. This is exactly as would be expected, because when the soil is completely saturated with water a steady state will be reached soon thereafter, when all the water which falls as rain must run off as surface water.

However, it might be argued that when the soil becomes completely saturated with water a greater volume of rain will remain upon the soil than previously soaked into the soil, and that equation (1) will not represent the behavior of the volume of rate of run-off after the soil is completely saturated. To investigate this, consider a lake or a pond. Assume that no water flows into the lake from the surrounding land. Rain falling upon such a lake will behave precisely as rain falling upon saturated level ground. Assume that the lake has one outlet, and that this outlet is sufficiently wide so that the discharge increases linearly with increase of the depth of the water flowing in the outlet. At the beginning of the rain we assume the lake to be just full, that is, there is no water flowing in the outlet. Under these conditions the heaviest rains of record would not cause the depth of water flowing in the outlet to reach a large value. Therefore the assumption that the discharge increases linearly with increase of depth of water flowing in the outlet is certainly valid.

Let h be the depth of water in the lake (and also in the outlet), measured from the height of the surface of the lake when the rain begins, at the time t. Let y be the discharge and let $y=\bar{c}h$ where $\bar{c}$ is a constant. Also let A be the area of the lake.

Now the volume of rainfall which has fallen up to time t, less the volume of water which to then has flowed away, is the volume remaining upon the lake; or in symbols:

$$\int_0^t Ardt-\int^t \bar{c}hdt=Ah.$$

Then by differentiating we get:

$Ardt-\bar{c}hdt=Adh$; solving for dt and integrating, $t=-\frac{A}{\bar{c}}\log (Ar-\bar{c}h)-\frac{A}{\bar{c}}\log K$. Now, multiplying by $-\frac{\bar{c}}{A}$, and combining terms, it follows from the definition of a logarithm that we can write:

$$e^{-\frac{\bar{c}}{A}t}=K(Ar-\bar{c}h).$$

As stated in words above, when $t=0$, then $h=0$, whence $K=\frac{1}{Ar}$. Therefore on substituting this value of K and solving for h, we have:

$$h=\frac{Ar}{\bar{c}}\left(1-e^{-\frac{\bar{c}}{A}t}\right).$$

Multiplying by $\bar{c}$ and recalling that $\bar{c}h=y$, we can write

$$y=Ar\left(1-e^{-\frac{\bar{c}}{A}t}\right).$$

This last equation is of exactly the same form as equation (1) and was derived not upon the assumption that the rate of run-off at any given time is proportional to the rainfall remaining upon the lake at that time, but upon the assumption that the discharge is proportional to the depth of water in the outlet. Under the stated conditions the depth of water in the outlet is never very large, and the assumption that the discharge is proportional to the depth of water in the outlet is then certainly valid.

From the above discussion of rain falling upon a lake, it will be clear to the reader that equation (1), which is based on the assumption that the rate of run-off at any given time is proportional to the rainfall remaining with the soil at that time, is rigorously true when the soil is completely saturated with water. However, equation (1) may not represent exactly the volume of rate of run-off when the soil is not completely saturated, because certain factors, e. g., capillary action and osmotic pressure (in the roots of plants), have been ignored. For the primary purpose of these articles it is believed that equation (1) is sufficiently accurate, certainly so as a first approximation, whether all the rain soaks into the soil, all remains upon the soil, or part soaks into the soil and part remains upon the soil.

The constant c, equation (1), depends upon the nature and condition of the soil. It does not vary during any particular rain but does vary from rain to rain, depending upon how much moisture the soil contains at the beginning of the rain and whether the ground is freshly tilled or fallow, covered with vegetation or bare, the kind of vegetation if covered, and whether or not the ground is frozen. Moreover, the constant c will change from area to area, depending upon the type of soil.

The constant c may be considered as consisting of two parts, say c' and c''; one, c', due to the fact that the soil is pervious and hence water soaks *into* the soil; and the other, c'', owing to the fact that not all the rain which does not soak into the soil flows off instantaneously, but a part remains *upon* the soil. When c is thus divided, the second part c'' not only remains constant during any particular rain but also from rain to rain for a given small area. The part c'' depends of course upon the precipitous nature of the land, being close to zero for steep slopes. Over generally level land, especially if many sloughs or hollows are present, c'' may have a rather high value. Neither c' nor c'' varies greatly from area to area so long as all the territory in question is of the same geological formation.

Equation (1) expresses the volume of rate of run-off as a function of the time while the rain continues. It may be termed the equation of rise. When the rain stops, the rate of run-off immediately decreases; equation (1) then no longer applies, but an equation of fall which will now be developed.

Let Z_0 be the volume of rate of run-off from the area A at the time the rain stops. Let $t'=t-t_0$ where t_0 is the duration of the rain. (Also, since $t=0$ when the rain begins, t_0 is the time that the rain stops.) Moreover t_0 is a constant; also when $t=t_0$ then $t'=0$ and $Z=Z_0$.

As in the equation of rise, it is assumed that at any time the rate of run-off is proportional to the rainfall remaining with the soil. That is to say, after the rain stops, the volume of rate of run-off at any time t is proportional to the volume which fell as rain, less the volume which ran off while it was raining, less the volume which has run off during the interval from the time the rain stopped to the time t. Now the volume which fell as rain is a constant, viz. AR, and the volume which ran off while it was raining is also a constant, say $F(t_0)$; whence we can write the previous sentence in symbols, thus: $cZ=AR-F(t_0)-\int_{t_0}^{t}Zdt$. (It may be well to point out that in this last equation the constant c has the same value for a given piece of ground as it had at the beginning of the rain, as in equation (1); and that $F(t_0)$ is the integral of equation (1) between the limits 0 and t_0.) Then, since the first two terms on the right-hand side of this last equation are constants, we have by differentiating: $cdZ=-Zdt$. Clearly, $dt=dt'$. Therefore $cdZ=-Zdt'$; and on dividing by cZ and integrating, $-\frac{t'}{c}=\log KZ$, whence from the definition of a logarithm we have:

$$KZ=e^{-\frac{t'}{c}}.$$

To evaluate the constant of integration K, put $Z=Z_0$ when $t'=0$; then $KZ_0=1$ or $K=\frac{1}{Z_0}$, and

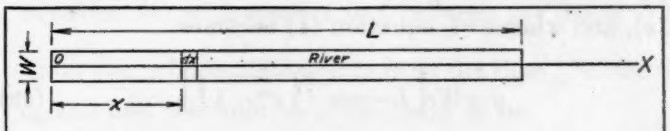
$$Z=Z_0e^{-\frac{t'}{c}}, \tag{2}$$

which is the equation of fall.

SECTION 2

As stated previously, equations (1) and (2) when regarded as expressing the volume of rate of run-off will be correct regardless of the size and shape of the drainage area. When regarded as expressing the discharge, equations (1) and (2) are correct only when the drainage area is small.

Consider now a large drainage area that is rectangular. Let W be the width and L be the length of the rectangle. (See fig. 1.) Let the gaging station be at the origin, and let the river coincide with the X-axis. Let x be the distance of each small (infinitesimal) element of area above the outlet (gaging station). Let v be the velocity of the moving surface water, and consider v to be constant. Let y be the discharge at time t at the gaging station, and let $t=0$ when the rain begins. Assume that the river is dry when the rain begins. Each infinitesimal area above the gaging station may be considered as contributing an infinitesimal portion to the discharge y at the gaging station. At time t each infinitesimal area contributes to y not its discharge at time t but its discharge at the time t diminished by the time required for its water to flow to the gage.



The gaging station is at the origin "O"
The river coincides with the X-axis
Distances to the right of O are positive
The river flows to the left

Figure 1

The time required for the water from an infinitesimal strip, Wdx, to flow to the gage is x/v, where x is the distance of the infinitesimal strip above the gaging station. Hence, it follows from equation (1) that, at time t, each infinitesimal area contributes a discharge of $Wr\left[1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right]dx$ to the discharge y at the gaging station. Now, y is the sum of the discharges from all of the infinitesimal areas above the gage and is therefore the integral of the above expression. If the interval from the beginning of the rain to the time t is so small that the water from the upper portions of the drainage area has not had time to reach the gage, the upper limit of the integral is not the length of the drainage area L but is that value of x such that $t=\frac{x}{v}$, i. e., it is that value of x such that the water from distance x has had just sufficient time to reach the gage. Hence, integrating the above expression from 0 to tv,

$$y=Wrv\left[t-c+ce^{-\frac{t}{c}}\right]. \tag{3}$$

Equation (3) expresses y as a function of t. When $t=0$ then $y=0$, and when $t=\frac{L}{v}$, then

$$y=Wr\left[L-cv+cve^{-\frac{L}{cv}}\right]. \tag{3a}$$

Equation (3) holds only on the range $0 \leqq t \leqq \frac{L}{v}$, with the further restriction that $t \leqq t_0$. It should be noted that t is not restricted to this range for any mathematical reasons, but because of the physical nature of the problem. During the interval $0 \leqq t \leqq \frac{L}{v}$ the discharge at the gaging station, y, is increasing from two causes: first, the soil in the drainage area is approaching the limit of its capacity for water, hence a greater and greater portion of the rain falling upon the drainage area is flowing off as free water; secondly, the area which contributes to y is increasing. As soon as the whole drainage area above the gage is contributing to y, then y increases from the first cause only.

Suppose $t \geqq \frac{L}{v}$ and also $t \leqq t_0$. Then integrating the same expression as before, from 0 to L now,

$$y=Wr\left[L-cve^{-\frac{t}{c}}\left(e^{\frac{L}{cv}}-1\right)\right]. \tag{4}$$

Equation (4) expresses y as a function of t and holds on the range $\frac{L}{v} \leqq t \leqq \infty$ with the restriction that $t \leqq t_0$. In other words, as long as it continues to rain, equation (4) applies. When $t=\frac{L}{v}$ equation (4) reduces to equation (3a), and when $t=t_0$ equation (4) becomes:

$$y=Wr\left[L-cve^{-\frac{t_0}{c}}\left(e^{\frac{L}{cv}}-1\right)\right]. \tag{4a}$$

Equations (3) and (4) are equations of rise. An equation of fall will now be derived. Suppose that $t > (t_0+\frac{L}{v})$. Then it follows from equation (2), by reasoning similar to the above, that

$$y=\int_0^L Wr\left[1-e^{-\frac{t_0}{c}}\right]e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}\,dx$$

in which expression the product $Wr\left[1-e^{-\frac{t_0}{c}}\right]dx$ is the discharge from the infinitesimal strip Wdx at the instant that the rain stops. Whence, by carrying out the indicated integration,

$$y=Wr\left[1-e^{-\frac{t_0}{c}}\right]cv\left[e^{-\frac{1}{c}\left(t'-\frac{L}{v}\right)}-e^{-\frac{t'}{c}}\right].$$

Then on putting $t'=t-t_0$:

$$y=Wrcv\left[e^{-\frac{1}{c}\left(t-t_0-\frac{L}{v}\right)}-e^{-\frac{1}{c}\left(t-t_0\right)}-e^{-\frac{1}{c}\left(t-\frac{L}{v}\right)}+e^{-\frac{t}{c}}\right]. \tag{5}$$

Equation (5) holds on the range $t_0+\frac{L}{v} \leqq t \leqq \infty$. When $t=t_0+\frac{L}{v}$ equation (5) becomes:

$$y=Wrcv\left[1-e^{-\frac{L}{cv}}-e^{-\frac{t_0}{c}}+e^{-\frac{1}{c}\left(t_0+\frac{L}{v}\right)}\right]. \tag{5a}$$

Also when $t=\infty$ then $y=0$; that is to say, when t is taken sufficiently large the discharge ceases.

An equation for the range $t_0 \leqq t \leqq \left(t_0+\frac{L}{v}\right)$ will now be obtained. $\left(\text{It is supposed that } t_0 > \frac{L}{v}\right)$. If $\left(t-\frac{x}{v}\right) < t_0$ the contribution of the area Wdx to the discharge at the gaging station is

$$dy=Wr\left[1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right]dx,$$

while if $\left(t-\frac{x}{v}\right) > t_0$ then the contribution of the area Wdx is

$$dy=Wr\left[1-e^{-\frac{t_0}{c}}\right]e^{-\frac{1}{c}\left(t-t_0-\frac{x}{v}\right)}dx.$$

Consider the time t, and select x_0 as the value of x such that $t-\frac{x}{v}=t_0$, i. e., $x_0=(t-t_0)v$.

Then:

$$y=\int_{x_0}^{L} Wr\left[1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right]dx+\int_0^{x_0} Wr\left[1-e^{-\frac{t_0}{c}}\right]e^{-\frac{1}{c}\left(t-t_0-\frac{x}{v}\right)}dx$$

$$=Wr\left[L-x_0+cv\left\{e^{-\frac{1}{c}\left(t-\frac{x_0}{v}\right)}-e^{-\frac{1}{c}\left(t-\frac{L}{v}\right)}+\left(1-e^{-\frac{t_0}{c}}\right)\left(e^{-\frac{1}{c}\left(t-t_0-\frac{x_0}{v}\right)}-e^{-\frac{1}{c}\left(t-t_0\right)}\right)\right\}\right].$$

But since $x_0=(t-t_0)\,v$ and $t-\frac{x}{v}=t_0$ the above reduces to:

$$y=Wr\left[L-(t-t_0)v+cv\left\{1+e^{-\frac{t}{c}}-e^{-\frac{1}{c}\left(t-\frac{L}{v}\right)}-e^{-\frac{1}{c}(t-t_0)}\right\}\right]. \tag{6}$$

Equation (6) holds on the range $t_0 \leqq t \leqq t_0+\frac{L}{v}$. When $t=t_0$ equation (6) reduces to equation (4a), and when $t=t_0+\frac{L}{v}$ equation (6) reduces to equation (5a). Equation (6) may be considered as a transition between equation (4) and equation (5). In equation (4) the contributions from all of the infinitesimal areas are increasing; in equation (5) the contributions from all of the infinitesimal areas are decreasing. Between these two cases lies equation (6), where the contributions from part of the infinitesimal areas are increasing while the contributions from the remainder are decreasing.

The time of the maximum discharge, i. e., the time of the flood crest, may be found by obtaining the first derivative of equation (6) with respect to t and equating it to zero. Thus:

$$\frac{dy}{dt}=Wr\left[-v+v\left\{-e^{-\frac{t}{c}}+e^{-\frac{1}{c}\left(t-\frac{L}{v}\right)}+e^{-\frac{1}{c}(t-t_0)}\right\}\right].$$

Designate the time of the crest stage by t_c; then:

$$-1-e^{-\frac{t_c}{c}}+e^{-\frac{1}{c}\left(t_c-\frac{L}{v}\right)}+e^{-\frac{1}{c}(t_c-t_0)}=0;$$

multiplying by $e^{\frac{t_c}{c}}$, and transposing,

$$e^{\frac{t_c}{c}}=e^{\frac{L}{cv}}+e^{\frac{t_0}{c}}-1,$$

whence

$$t_c=c\log\left(e^{\frac{L}{cv}}+e^{\frac{t_0}{c}}-1\right). \tag{7}$$

Setting $t=t_c$ in equation (6), and noting that this equation can be written

$$y=Wr\left[L-(t-t_o)v+cve^{-\frac{t}{c}}\left\{e^{\frac{t}{c}}+1-e^{\frac{L}{cv}}-e^{\frac{t_0}{c}}\right\}\right],$$

it follows that the maximum discharge, y_c, is given by the equation:

$$y_c=Wr[L-(t_c-t_o)v]. \tag{8}$$

Equations (7) and (8) were derived from equation (6), and in turn equation (6) was developed on the assumption that $t_0>\frac{L}{v}$. The question arises whether equations (7) and (8) hold when $t_0<\frac{L}{v}$. Suppose that $t_0<\frac{L}{v}$. Then equation (3) will hold only on the range $0\leqq t\leqq t_0$ because as soon as the rain stops (when $t=t_0$) the contributions from the portions of the drainage area near the gage at once begin to decrease, and if $t_0<\frac{L}{v}$ the contributions from the upper portions of the drainage area have not yet reached the gage so that equation (6) does not apply either. When $t>t_0$ the contributions from the lower part of the drainage area are decreasing, and the discharge at the gaging station is given by:

$$y=\int_{x_0}^{tv} Wr\left[1-e^{-\frac{1}{c}\left(t-\frac{x}{v}\right)}\right]dx+\int_0^{x_0} Wr\left[1-e^{-\frac{t_0}{c}}\right]e^{-\frac{1}{c}\left(t'-\frac{x}{v}\right)}dx,$$

where x_0 is that value of x such that $(t-t_0)v=x_0$, and where $t'=t-t_0$. Whence:

$$y=Wr\Big[tv-cv-x_0+cve^{-\frac{1}{c}\left(t-\frac{x_0}{v}\right)}$$
$$+\left(1-e^{-\frac{t_0}{c}}\right)\left(cve^{-\frac{1}{c}\left(t-t_0-\frac{x_0}{v}\right)}-cve^{-\frac{1}{c}(t-t_0)}\right)\Big],$$

and on putting $x_0=(t-t_0)\,v$,

$$y=Wrv\left[t-c-(t-t_0)+c\left\{e^{-\frac{t}{c}}+\left(1-e^{-\frac{t_0}{c}}\right)\left(1-e^{-\frac{1}{c}(t-t_0)}\right)\right\}\right],$$

or

$$y=Wrv\left[t_0+c\left\{e^{-\frac{t}{c}}-e^{-\frac{1}{c}(t-t_0)}\right\}\right]. \tag{9}$$

Equation (9) holds only on the range $t_0\leqq t\leqq\frac{L}{v}$. When $t=t_0$ equation (9) becomes:

$$y=Wrv\left[t_0+c\left\{e^{-\frac{t_0}{c}}-1\right\}\right]; \tag{9a}$$

and when $t=\frac{L}{v}$ equation (9) takes the form:

$$y=Wrv\left[t_0+c\left\{e^{-\frac{L}{cv}}-e^{-\frac{1}{c}\left(\frac{L}{v}-t_0\right)}\right\}\right]. \tag{9b}$$

Equation (9) does not have a maximum within the range for which it holds, because its derivative is

$$Wrve^{-\frac{t}{c}}\left\{e^{\frac{t_0}{c}}-1\right\},$$

and on putting this derivative equal to zero we obtain $t=\infty$, which is beyond the range for which equation (9) holds.

Now when $t=t_0$ equation (3) reduces to equation (9a), and also when $t=\frac{L}{v}$ equation (6) reduces to equation (9b). Thus equation (9) is a transition between equations (3) and (6); and when $t_0<\frac{L}{v}$ and $t>\frac{L}{v}$ the discharge is given by equation (6). As equation (9) has no maximum it follows therefore, whether $t_0\gtrless\frac{L}{v}$, that equation (7) gives the time of the crest, and equation (8) gives the maximum discharge. In other words, regardless of how short or long the rain lasts, equations (7) and (8) apply.

A method of showing that equations (3), (4), (5), and (6) are correct is to integrate them between the limits of the respective ranges for which they apply, and ascertain that the sum of the four integrals thus obtained is equal to the volume of rainfall which occurs over the drainage area.

In carrying out the above procedure we first obtain the volume of discharge for the period from $t=0$ to $t=\frac{L}{v}$ by integrating the right-hand side of equation (3) with respect to t, thus:

$$\int_0^{\frac{L}{v}} Wrv\left[t-c+ce^{-\frac{t}{c}}\right]dt=$$
$$Wrv\left[\frac{L^2}{2v^2}-\frac{cL}{v}-c^2e^{-\frac{L}{cv}}+c^2\right]. \tag{A}$$

In a similar manner we integrate the right-hand side of equation (4) with respect to t between the limits $\frac{L}{v}$ and t_0, for the volume of discharge from the time $\frac{L}{v}$ to the time t_0, and find this volume of discharge to be

$$Wr\left[Lt_0+c^2ve^{-\frac{1}{c}\left(t_0-\frac{L}{v}\right)}-c^2ve^{-\frac{t_0}{c}}-\frac{L^2}{v}-c^2v+c^2ve^{-\frac{L}{cv}}\right]. \tag{B}$$

Likewise for the period from $t=t_0$ to $t=t_0+\frac{L}{v}$, the integration of the right-hand side of equation (6) with respect to t between these limits gives

$$Wr\Big[\frac{L^2}{2v}+cL-c^2ve^{-\frac{1}{c}\left(t_0+\frac{L}{v}\right)}+c^2ve^{-\frac{L}{cv}}-c^2v-c^2ve^{-\frac{1}{c}\left(t_0-\frac{L}{v}\right)}$$
$$+2c^2ve^{-\frac{t_0}{c}}\Big]. \tag{C}$$

Finally, integrating the right-hand side of equation (5) for the period $t=t_0+\frac{L}{v}$ to $t=\infty$ (at the time $t=\infty$ the discharge at the gaging station has receded to its value at the time that the rain began, viz., $y=0$) we get:

$$Wrc^2v\left[1-e^{-\frac{L}{cv}}-e^{-\frac{t_0}{c}}+e^{-\frac{1}{c}\left(t_0+\frac{L}{v}\right)}\right]. \tag{D}$$

The sum of expressions (A), (B), (C), and (D) is $WLrt_0$ and is the volume of discharge during the interval between the time $t=0$ (when the rain began) and the time $t=\infty$ (actually when the river again becomes dry). It will be noted that the volume of discharge is the area of the basin times the rate at which the rain falls times the duration of the rain, and is the volume of rainfall. This result is exactly what should be expected when evaporation is neglected.

Expressions (A), (B), (C), and (D) result when it is assumed that $t_0>\frac{L}{v}$. In a similar manner we can obtain other expressions from equations (3), (9), (6), and (5),

and show that when $t_0 < \frac{L}{v}$ the volume of discharge equals $WLrt_0$.

In the above development it was assumed that the river was dry when the rain began. Actually this condition seldom occurs in nature. However, it will be clear to the reader that this assumption was made for simplicity, and was not at all essential for the above development. If the river is not dry at the time the rain begins, then the discharge at time t is given by the sum of the right-hand side of one of equations (3), (4), (5), (6), or (9) (the one whose range includes t) and the discharge when the rain begins. Obviously, it is necessary to assume here that the river is at a steady state when the rain begins.

ACKNOWLEDGMENT

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THE SNOW SURVEY AS AN INDEX TO SUMMER PRECIPITATION [1]

By O. W. MONSON

[Montana State College Agricultural Experiment Station, Bozeman, June 1934]

The successful prediction of rainfall, whether it be a single storm or the accumulation for the entire season, involves a knowledge of where the rainstorms originate and the paths they follow. The exact origin of the rain that falls at a given place cannot be definitely traced, but it is the opinion of reliable authorities that as we advance inland from the ocean the percentage of the moisture in the air which originates directly from the ocean becomes smaller.

The following is quoted from "Forests and Water in the Light of Scientific Investigation," by Raphael Zon:

> The precipitation over the land does not depend solely on the amount of water brought as vapor by the prevailing winds from the ocean. * * * The moisture-laden currents soon lose the moisture which they obtain directly from the ocean, but in moving farther into the interior absorb the evaporation from the land. Hence, the farther from the ocean the greater is the proportion which evaporation from the land forms of the air moisture.

Adolph Meyer says:

> It is a common misconception that almost all of the rain which falls on the land comes from moisture evaporated from the ocean. As a matter of fact, the greater portion of the rain which falls in the United States is water reprecipitated after having fallen as rain (or snow) and having evaporated from the land area. (Elements of Hydrology.)

According to these authorities, much of the water which falls as rain at inland points has been evaporated from the residual of previous precipitation not accounted for by run-off or deep percolation. Therefore, the amount of precipitation that occurs at a given place should depend to a great extent upon the moisture conditions on the lands over which the prevailing winds at that point blow. Moisture is picked up from lakes, reservoirs, streams, snow fields, and from swamps and other moist lands. How much is contributed by each should depend, among other things, upon its relative extent.

On the theory that conditions which affect the extent of one of these sources will affect all in about the same proportion, a preseason measurement of the extent of one or more of the above-named sources of moisture should be an index to the amount of summer rainfall at various places located in the path of the moisture-bearing winds.

To test this theory the writer made comparisons between the water content of the snow cover on the watershed of Swiftcurrent Creek of the St. Mary River drainage basin measured early in May and the amount of rain occurring during April, May, June, July, and August at Havre, Geraldine, and other places located eastward from the snow fields. See figure 1.

The water content in inches of the snow cover in the Swiftcurrent cir ue of the St. Mary River Basin was plotted for the 12-year period of record from 1922 to 1933, inclusive. The summer rainfall in inches for the several places mentioned was plotted for the same period, and the water content curve was then compared with each rainfall curve to discover if any correlation existed.

A marked similarity was observed in the fluctuations when the water-content curve was compared with the rainfall curves for Havre and Geraldine, as shown in figure 2. The rainfall record at Havre and Geraldine during April, May, June, July, and August and the water content of the snow cover in the Swiftcurrent basin measured on May 1 of each year are given in table 1.

Correlation coefficients calculated between the water content of the snow in the Swiftcurrent basin and the rainfall during April 1 to August 31 at Havre and at Geraldine give values of 0.72 for Havre and 0.71 for Geraldine, which is a high degree of correlation. This apparent relation between the water content of snow in the Swiftcurrent basin and the summer rainfall at Havre is expressed by the equation $R=0.177W+4.74$, where R equals inches of rainfall and W is the water content of the snow cover in inches. The equation representing the best fit line for Geraldine is $R=0.155W+4.05$.

The reliability of this correlation is limited by the paucity of data available over a short period of record, 12 years. To be conclusive, a much longer period should be studied. Snow surveys are a comparatively recent innovation, but their value is rapidly being recognized.

By means of these two equations the summer rainfall at Havre and Geraldine was calculated for the 12-year period from the water-content measurements in the Swiftcurrent basin and the estimated amount compared with the actual record as in figures 3 and 4. The similarity of the curves is remarkable. It may be noted that the slope of the estimated curves, that is, up or down, showing increase or decrease as compared with the previous year, is correct 11 out of 12 years for Geraldine and 10 out of 12 years for Havre, and that a forecast of "above normal" or "below normal" would have been correct in 10 out of the 12 years for each place.

But this correlation does not necessarily prove a direct causal relationship between the snow cover on the St. Mary River watershed and the summer rainfall at Havre and Geraldine. Perhaps they are associated as kindred effects of a third factor, or perhaps they show similar variations because affected by other similar though distinct underlying influences. This, however, does not detract from the practical value of the apparent relationship.

[1] Contribution from Montana State College, Agricultural Experiment Station. Paper No. 40, Journal Series.

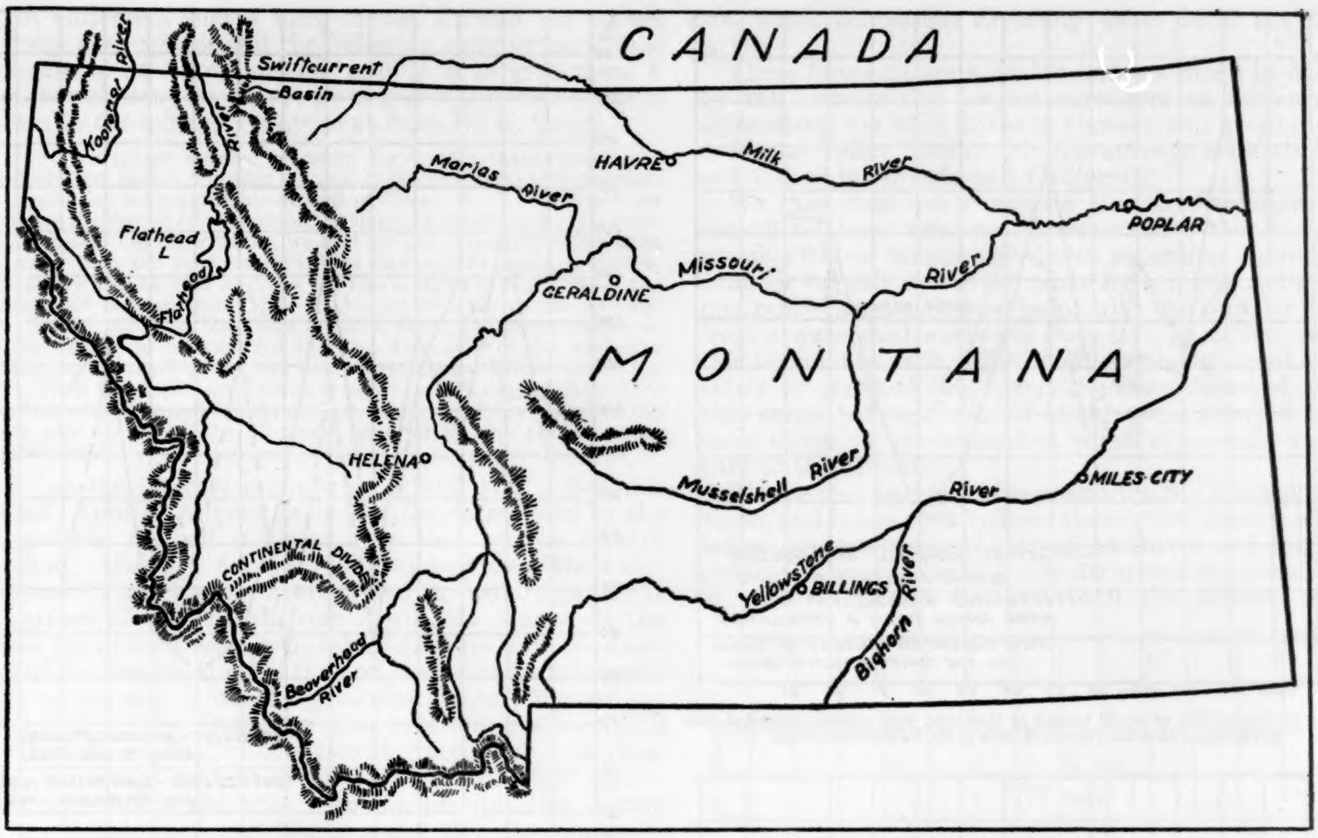


FIGURE 1.—Map of Montana showing the principal drainage systems and the location of the rainfall stations referred to.

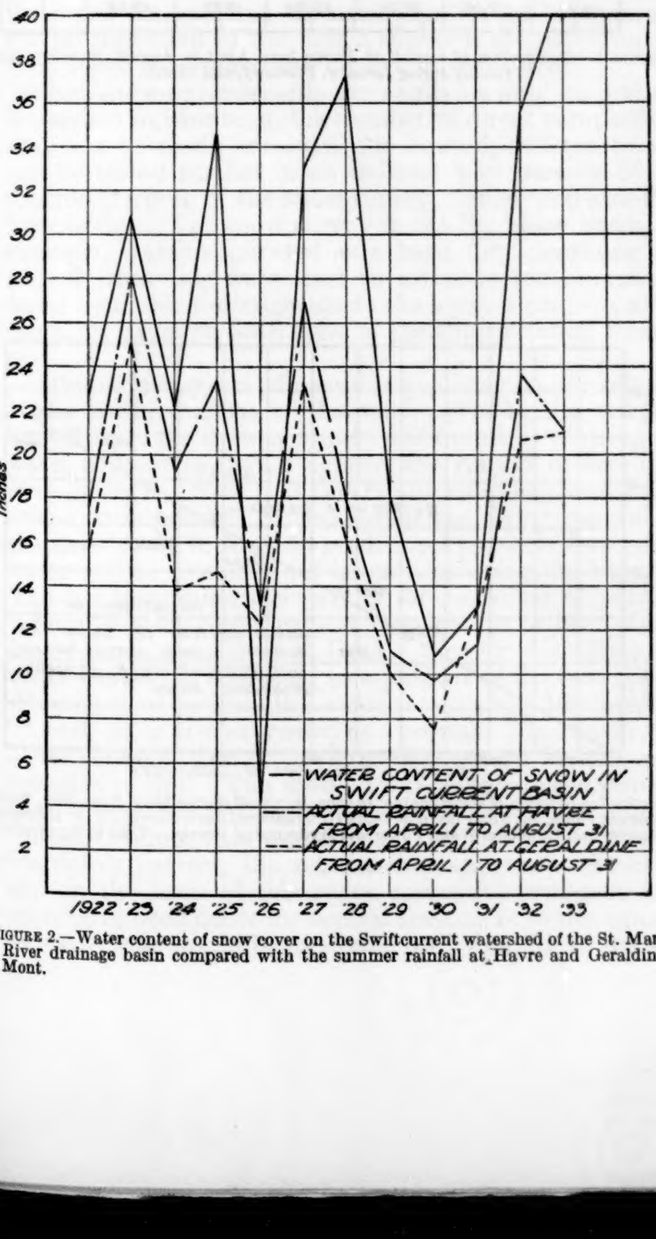


FIGURE 2.—Water content of snow cover on the Swiftcurrent watershed of the St. Mary River drainage basin compared with the summer rainfall at Havre and Geraldine, Mont.

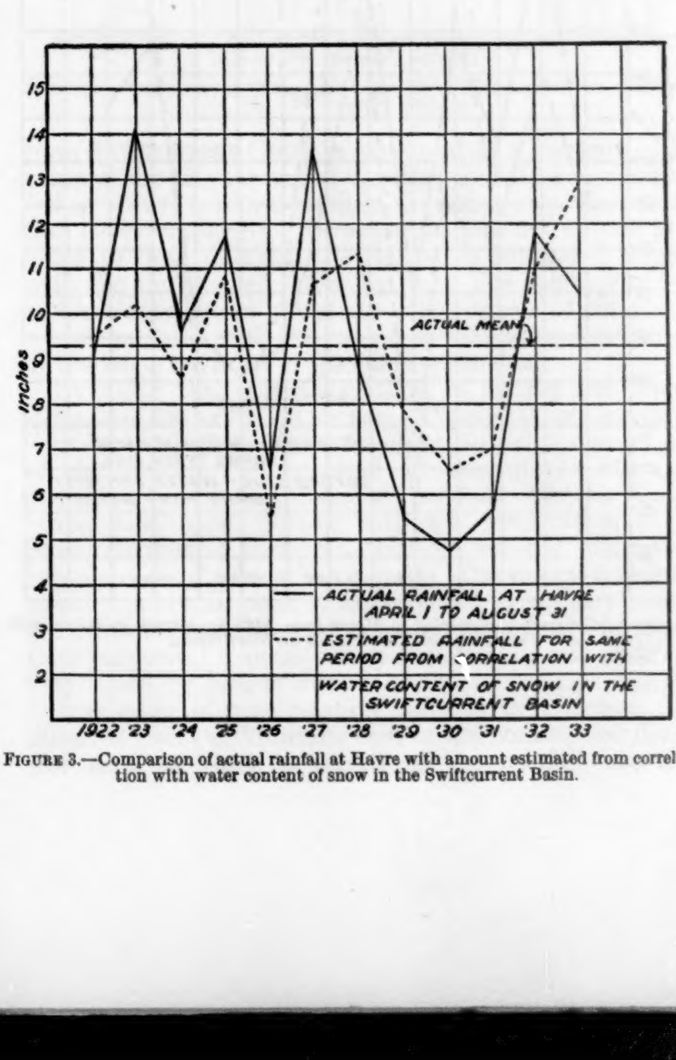


FIGURE 3.—Comparison of actual rainfall at Havre with amount estimated from correlation with water content of snow in the Swiftcurrent Basin.

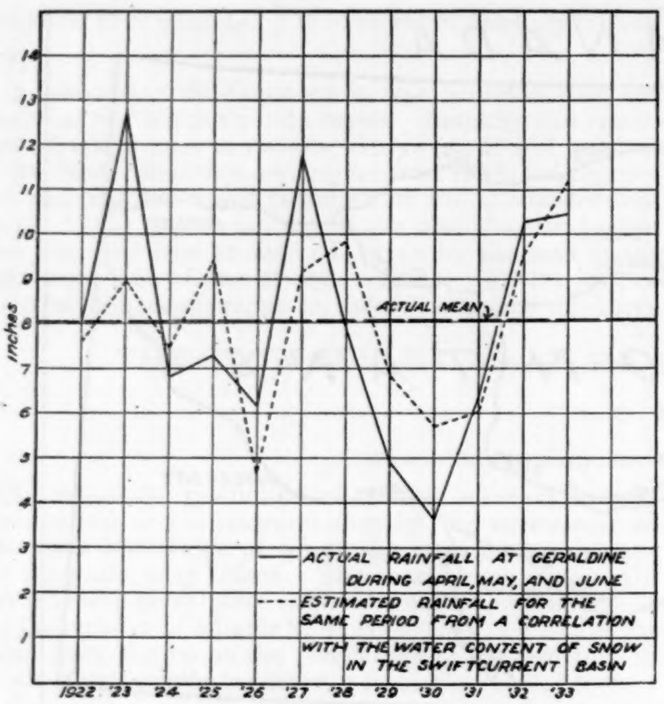


FIGURE 4.—Comparison of actual rainfall at Geraldine with amount estimated from correlation with water content of snow in the Swiftcurrent Basin.

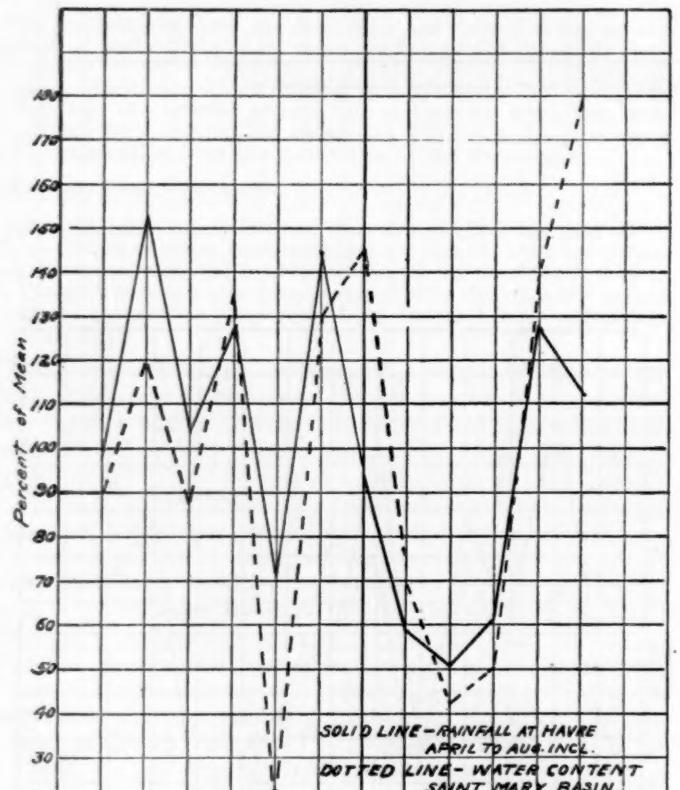


FIGURE 5.—Comparison of rainfall at Havre from April to August, inclusive, with water content of snow in the St. Mary Basin.

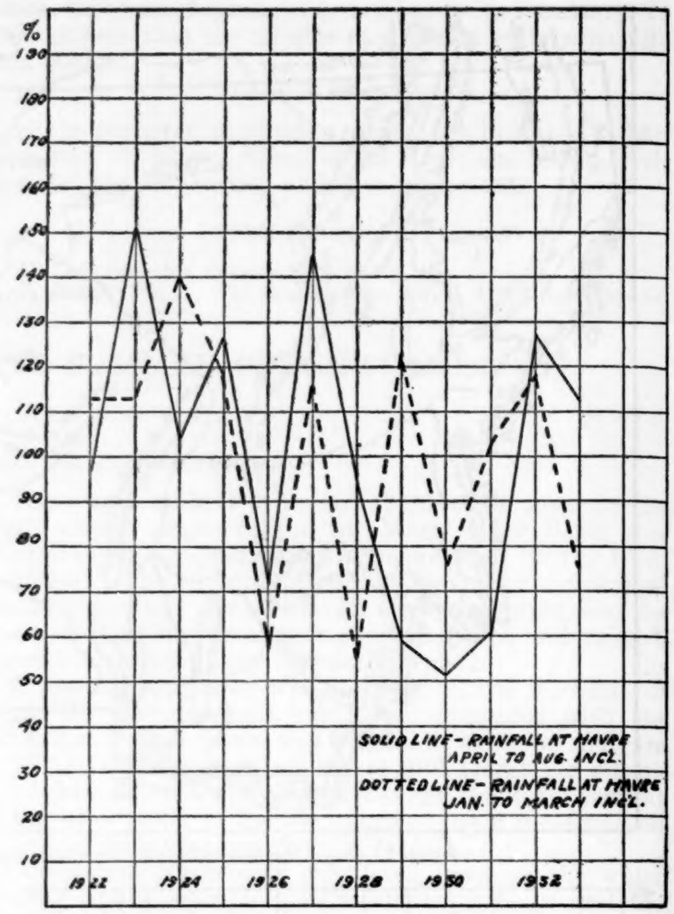


FIGURE 6.—Comparison of rainfall at Havre from April to August, inclusive, with rainfall during January, February, and March.

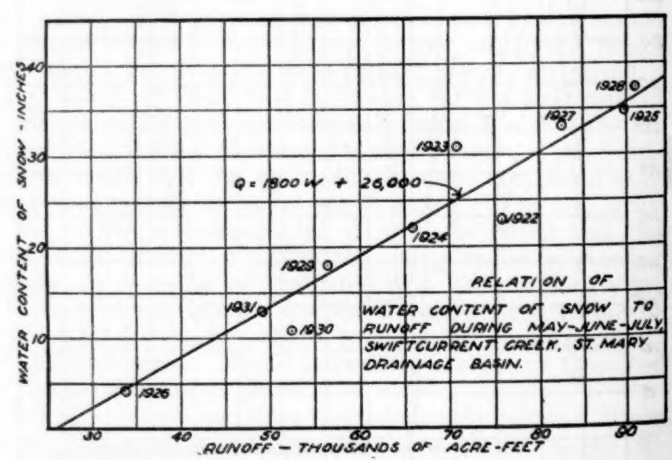


FIGURE 7.—Relation of water content of snow to run-off during May, June, July, Swiftcurrent Creek, St. Mary drainage basin (International Snow Survey, U. S. Geological Survey and Dominion Water Power and Hydrometric Bureau. Used by permission).

An indication that a third factor, a trend that tends to keep both winter and the following summer precipitation above or below normal, and thus to give them a high correlation, may be operating as a common cause is shown in the following statement from W. R. Gregg.

> There is a rather marked tendency for certain characteristics of precipitation, that is, whether tending to above normal or to dryness, to persist for a considerable period of time. * * * When we examine the record for Havre alone, without reference to the question of mountain snow water, we find for the period for which data are used that the precipitation from January to April, inclusive, was above the 12-year average six times, and for these years the subsequent rainfall from May to August was above the average five times. Also for the other 6 years, when the precipitation at Havre was below average for the first 4 months of the year, the subsequent 4 months also had below average five times out of the six. Thus the departure from average precipitation at Havre for the first 4 months and for the second 4 months of the year had the same sign in 10 of the 12 years covered by the period under consideration.

When the forecast is made to extend over a 5-month period, April to August, inclusive, the correlation by the snow-cover method is closer than that by the rainfall method. (See figs. 5 and 6.) The departure of the water content for the 12-year average had the same sign as the departure of the rainfall from April 1 to August 31 ten years out of the twelve, while the departure from the average of the precipitation of the first 3 months had the same sign as the next 5 months' precipitation only 8 years out of the 12. (The coefficient of correlation of the rainfall at Havre during the 3-month period, April, May, and June, with the water content of snow on the St. Mary watershed was 0.685, and that with the precipitation during January, February, and March was 0.51.) It is interesting to note that when the departure from the average of the water content had the same sign as the departure of the precipitation of the first 3 months, the precipitation from April to August was always in agreement.

Since snow-cover records are available only on a single watershed in Montana, the number of direct comparisons that can be made necessarily is limited, but the theory can be tested further in an indirect way because of the original purpose of the snow survey, namely, stream-flow forecasting. The snow survey in the St. Mary basin, for example, was inaugurated as a basis for forecasting the run-off from this watershed to estimate the amount of water available for irrigation to the various projects along the Milk River on both sides of the International Boundary.

After several years of record were obtained, the relation of the water content of the snow cover to the summer run-off from the drainage basin was found by plotting the water content in inches against the run-off in acre-feet, as in figure 7. Now that this relationship has been determined, it is possible by measuring the water content of the snow early in May to predict very closely how much water will be available for irrigation during the summer. This has been done successfully for a number of years.

Similar snow-cover run-off relations have been determined for Logan River in Utah. (See fig. 8.) Here the water content is expressed as a percent of the average for the period of record, the average equaling 100 percent. The run-off is also expressed as a percent of the mean run-off in acre-feet during the irrigation season for the same period of record. This method was chosen on the assumption that a normal snow cover will produce a normal run-off. While this assumption has not proved to be absolutely correct, the relationship appears to be close, and on the basis of this curve successful preseason forecasts have been made for several seasons as to the amount of water that would be available for irrigation to the several canal companies diverting water from the Logan River.

These forecasts are valuable and are much in demand by the farmers and project managers on the irrigated areas along the Milk River in Canada and Montana and in Cache Valley, Utah. Similar surveys have also been established in Nevada and California.

We may reasonably assume that similar snow-cover run-off relations exist on all watersheds; therefore, it is possible to test further the theory regarding the origin of summer rainfall at a given place by comparing the summer rainfall at the desired point with the summer run-off from a watershed westward from it. Then, if a correlation is found to exist, other conditions being equal, it may safely be assumed that about the same degree of correlation exists between rainfall at the place referred to and snow cover on the watershed which apparently contributes to the run-off.

This is true between Havre and the St. Mary drainage basin, and it has already been shown that there is a correlation between summer rainfall at Havre and the water content of snow cover in the Swiftcurrent watershed of the St. Mary drainage basin. When the summer run-off

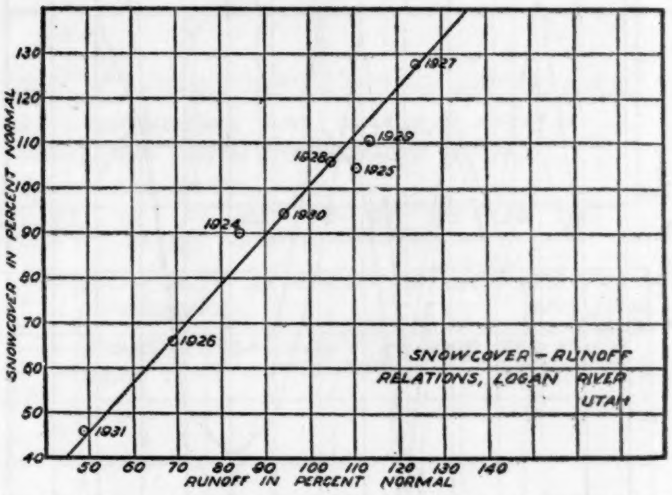


FIGURE 8.—Snow cover run-off relations, Logan River, Utah (Agricultural Engineering for February 1932).

from Swiftcurrent Creek is expressed as a percent of the mean of the 12-year period of record and the summer rainfall at Havre is represented in the same way, the correlation is also apparent. However, it does not appear to be quite so close as when the rainfall is compared directly with the snow cover. (See fig. 9.) The summer rainfall at Geraldine shows about the same degree of correlation when compared with the run-off as with the water content of the snow cover from the same watershed.

By using this indirect method of testing the theory, more data are available for use. Precipitation records are kept by the United States Weather Bureau for every part of the State. The principal streams of the State are gaged and records published annually by the United States Geological Survey with the cooperation of the State engineer. However, run-off records are not as complete as the weather report. On many important streams only short and in some cases fragmentary records are available and these are not complete enough for statistical purposes. Consequently the study is still restricted very much by lack of data.

A number of precipitation stations were chosen from different parts of Montana east of the continental divide. For each of these a record of the rainfall occurring

during April, May, June, July, and August was obtained for a period of 20 years, 1911 to 1930, inclusive. The mean for this period was calculated and summer rainfall for each year expressed as a percent of this mean.

The summer run-off from several streams was obtained from hydrographic reports for the same 20-year period and the 20-year mean was determined. Each year's run-off was then expressed as a percent of the 20-year mean for that stream, as was done for the precipitation stations.

These precipitation and run-off records were then plotted, and since each was expressed as a percent of its mean the rainfall records were all comparable with the run-off records. By comparing each rainfall curve with each of the run-off curves in turn, any existing correlation was quickly discovered.

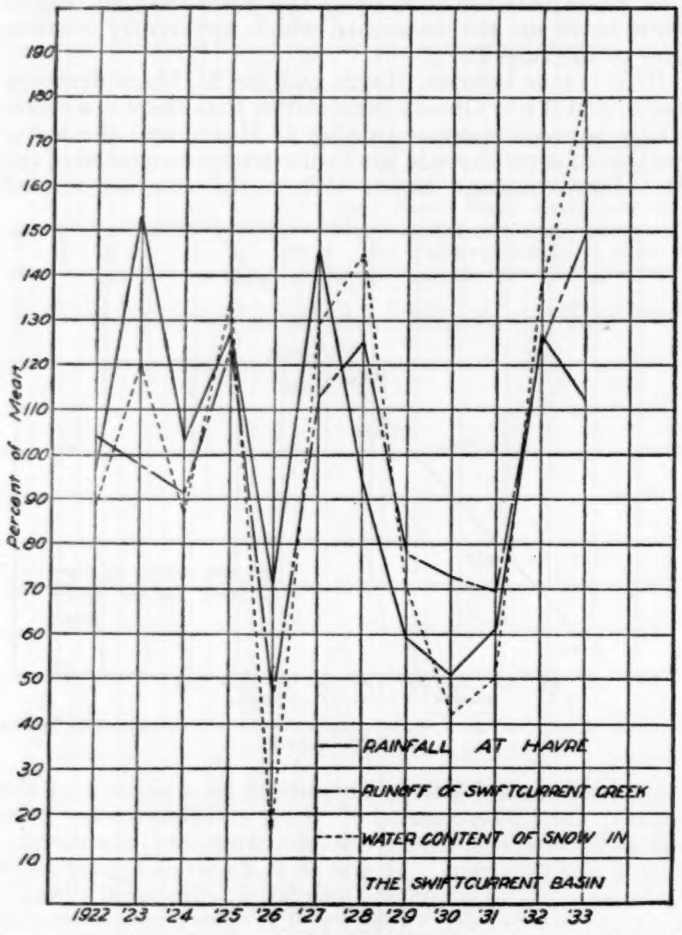


FIGURE 9.—Rainfall at Havre compared to run-off of Swiftcurrent Creek and to water content of snow in the Swiftcurrent Basin.

In this way similarity was discovered between the rainfall curve at Miles City and the run-off curve from the Beaverhead River. The rise or fall was almost identical for the two curves during a 7-year period from 1918 to 1924; and for four more years, 1925 to 1928, an increase or decrease in run-off from the Beaverhead River was reflected in an increase or decrease in summer rainfall at Miles City. Assuming that the run-off from the Beaverhead could be forecast by means of the snow survey, it could be used to predict the amount of summer rainfall at Miles City, as shown in figure 10, by multiplying the estimated percent of mean run-off by 8.55, which is the mean rainfall at Miles City, and dividing by 100.

Why there is such a high degree of correlation for 11 successive years from 1918 to 1928 and none at all from 1912 to 1918 nor during 1929 and 1930 cannot be explained from the data at hand. It may be that conditions which affect the extent or amount of one of the sources of the summer rainfall at Miles City do not affect all in the same proportion and therefore the assumption previously stated to that effect may be erroneous. But it is also possible that a record of the water content of snow cover on the Beaverhead watershed would show a higher degree of correlation with the rainfall than does the run-off, because the accuracy of the run-off records is affected to some extent by diversions and regulations above the gaging station. The rainfall at Havre, for example, showed a closer correlation to the snow cover than to the run-off from the Swiftcurrent basin.

When the rainfall at Miles City for the period April to August, inclusive, is compared with the rainfall for January, February, and March we find that the departure from the average has the same sign 12 years out of 20. When compared with the run-off from the Beaverhead River, the rainfall at Miles City for April to August falls on the same side of the average as the run-off 14 out of 20 years. But when the rainfall for April to June, inclusive, is compared with that of the first 3 months the departure has the same sign 16 out of 20 years (see fig. 11), while the coefficient of correlation in this case is only 0.17. The coefficient of correlation of the rainfall at Miles City during April, May, and June with the run-off of the Beaverhead River is 0.42.

These facts illustrate still further that correlation may exist with or without causal relationship. To discover a direct casual relationship, if such exists, will solve the problem of seasonal forecasting, but in the meantime these apparent correlations will be found both interesting and profitable.

The rainfall at a given place frequently cannot be correlated with run-off from a single watershed. This should not be expected from the very complex nature of the problem. It was found in the case of Helena that no single run-off curve could be found among those studied which showed very much similarity to the rainfall curve at Helena. But when the average run-off of the Beaverhead and Musselshell Rivers was taken in percent of their individual means, the resulting curve showed considerable similarity to the rainfall curve for Helena, and an estimated rainfall curve based on this correlation fluctuates up and down in sympathy with the actual rainfall curve from 1918 to 1929, inclusive, as shown in figure 12. The calculated amount agrees closely with the actual amount during 9 out of the 20 years of record; and during 16 of the 20 years the calculated value and the actual value fall on the same side of a horizontal line drawn through 7.4, the mean at Helena.

Similiarly, the rainfall curve at Billings, while showing very little correlation to any single run-off curve, showed a fair degree of resemblance to a curve derived from the average run-off of the Yellowstone, Beaverhead, and Priest Rivers. The calculated amount of summer rainfall at Billings, as given in figure 13, was obtained by multiplying the mean summer rainfall, 8.1 inches, by the average percent, based on the mean of each stream, of the run-off from these three streams and dividing by 100.

The rainfall curve at Poplar also was not successfully correlated with any one run-off curve although some similarity was observed when it was compared with an average of the Big Horn and Marias Rivers shown in figure 14, where an estimated rainfall curve is compared with the actual. The correlation is poor, although the estimated amount agrees with the actual within practical limits for 9 out of the 16 years of record.

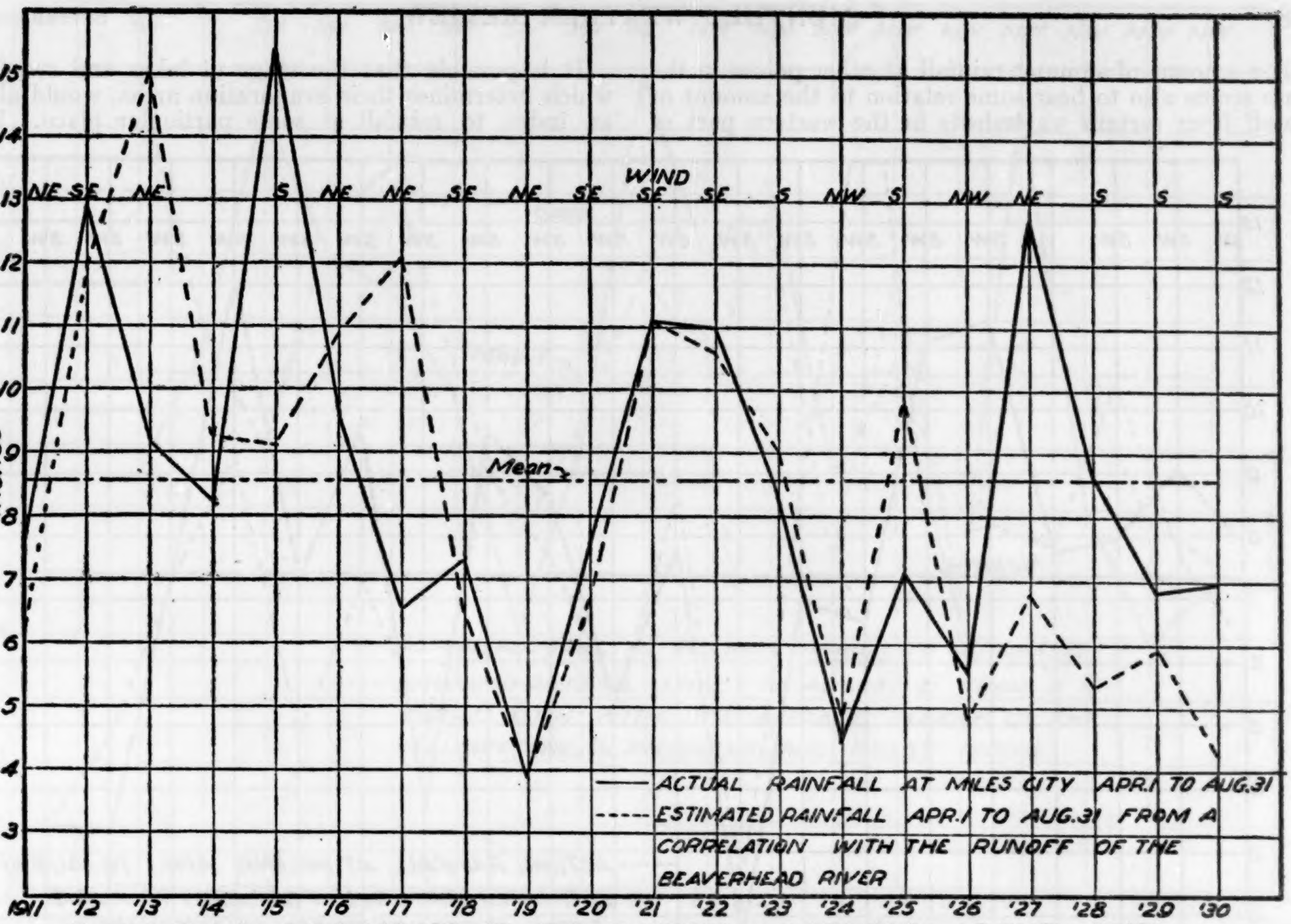


FIGURE 10.—Comparison of actual rainfall at Miles City with amount estimated from a correlation with the run-off of the Beaverhead River.

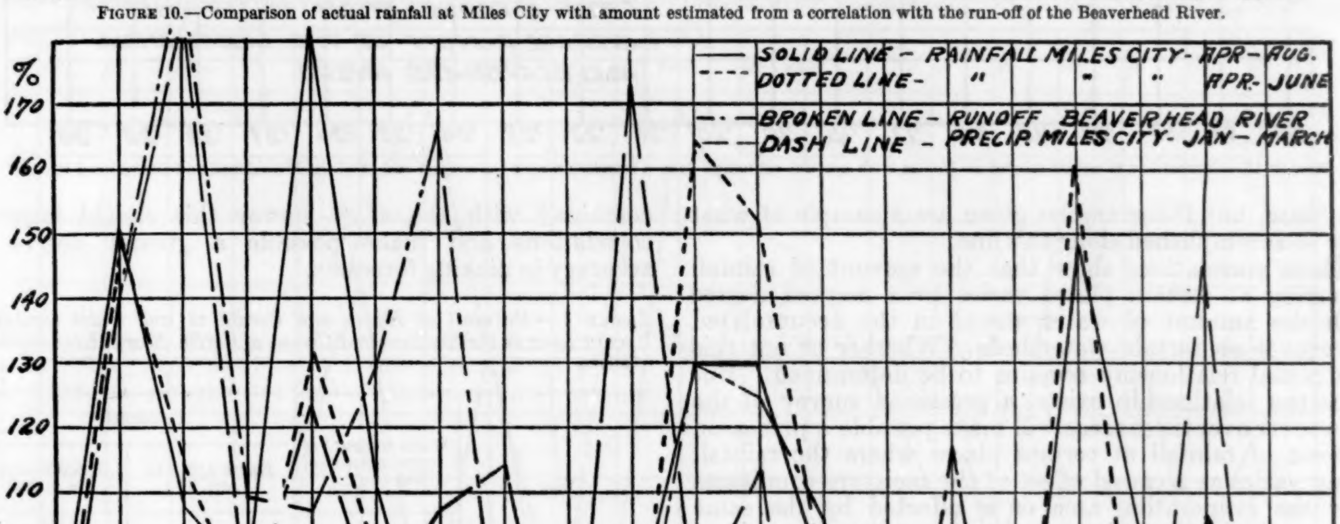


FIGURE 11.—Comparison of actual rainfall at Miles City from April to August, inclusive, and from April to June, inclusive, with run-off from the Beaverhead River and with the precipitation during January, February, and March.

The amount of summer rainfall at other points in the State seems also to bear some relation to the amount of run-off from certain watersheds in the western part of the State, but the examples given are a sample of what may be accomplished along this line.

These correlations show that the amount of rainfall occurring at certain places varies to a marked degree with the amount of water stored in the accumulated snowcover on certain watersheds. Whether or not this is a causal relationship remains to be determined. But since the relationship exists, a preseason survey of the snowcover over these areas will make possible a preseason forecast of rainfall at certain places where the rainfall either varies as a causal effect of the moisture conditions over the evaporation area or is affected by the same factors which affect these moisture conditions.

Because of these correlations, it appears that a comprehensive snow survey on all watersheds would show other water-content rainfall relations from which it would be possible to predict, several months in advance, the amount of rainfall likely to occur during the summer at many places, some of which may be a great distance from the related watershed. The value of the snow survey for predicting run-off has already been demonstrated. Other information concerning the behavior of the snow blanket could also be obtained from the snow survey, which might suggest ways of improving the watersheds so as to reduce, if not eliminate, the dissipation of snowcover through too rapid melting and wasteful run-off.

It is possible that the stage of lakes and reservoirs, which determines their evaporation areas, would also be an index to rainfall at some particular place. When combined with the snow survey this should improve correlations and make possible a greater degree of accuracy in making forecasts.

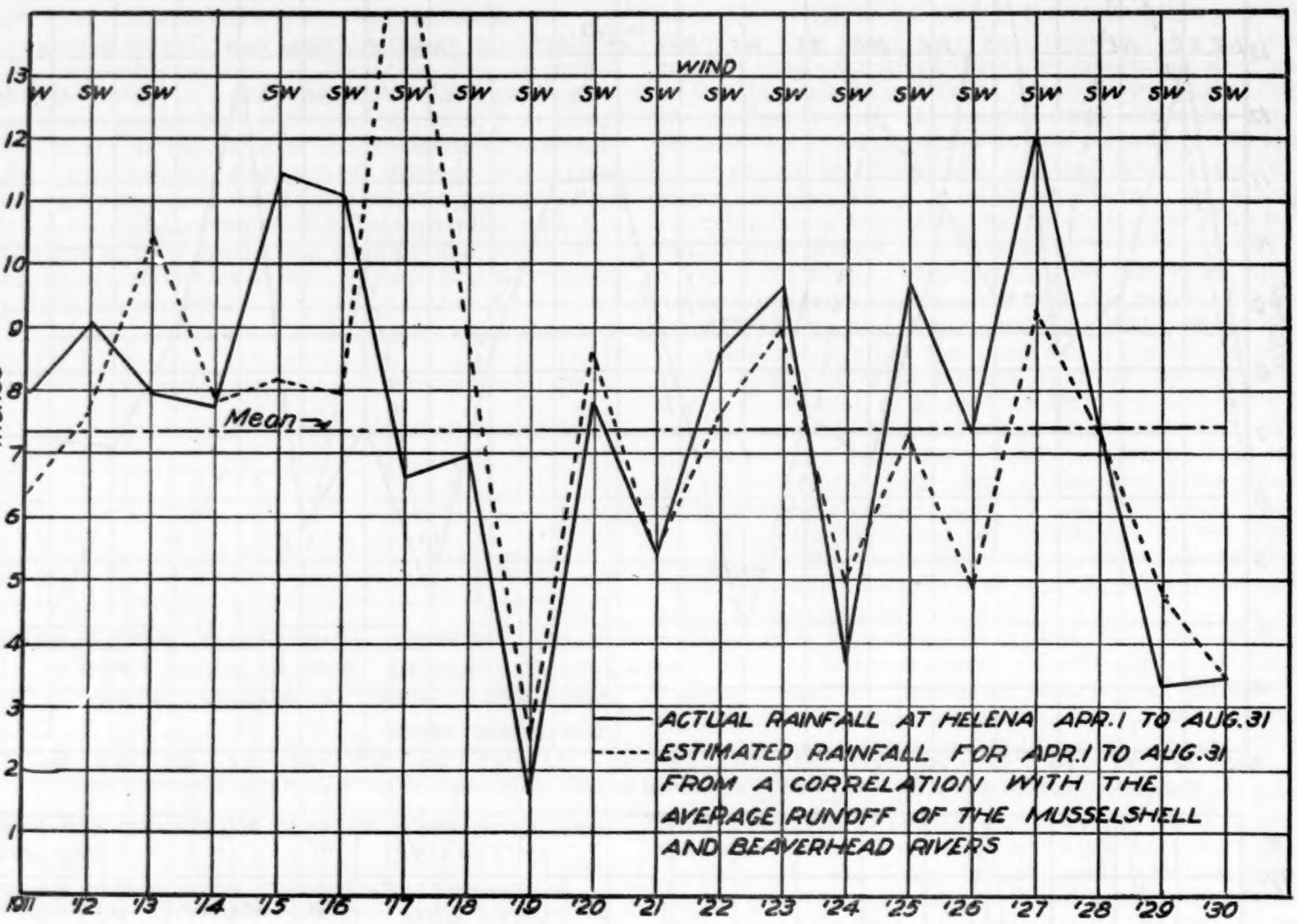


FIGURE 12.—Comparison of actual rainfall at Helena with amount estimated from a correlation with the average run-off of the Musselshell and Beaverhead Rivers.

TABLE 1.—*Rainfall at Havre and Geraldine and water content of snow cover in the Swiftcurrent Cirque of the St. Mary River drainage basin*

Year	Water content [1] of snow cover as of May 1		Rainfall [2]			
			Havre Apr. 1 to Aug. 31		Geraldine Apr. 1 to Aug. 31	
	Inches	Percent of mean	Inches	Percent of mean	Inches	Percent of mean
1922	22.8	89	8.86	96	7.94	98
1923	30.9	120	14.18	153	12.74	158
1924	22.0	86	9.63	104	6.83	85
1925	34.9	136	11.76	127	7.30	91
1926	4.1	16	6.56	71	6.18	77
1927	33.2	129	13.50	145	11.86	147
1928	37.4	146	8.73	94	7.96	99
1929	18.1	70	5.49	59	4.87	61
1930	10.7	42	4.75	51	3.65	45
1931	12.9	50	5.69	61	6.53	81
1932	35.6	138	11.83	127	10.32	128
1933	46.2	180	10.44	112	10.45	130
Mean	25.7		9.28		8.05	

[1] Water content of snow measured by the U. S. Geological Survey in cooperation with the Dominion Water Power and Hydrometric Bureau, available through the courtesy of W. A. Lamb, of the U. S. Geological Survey.
[2] Rainfall records from the annual reports of the U. S. Weather Bureau.

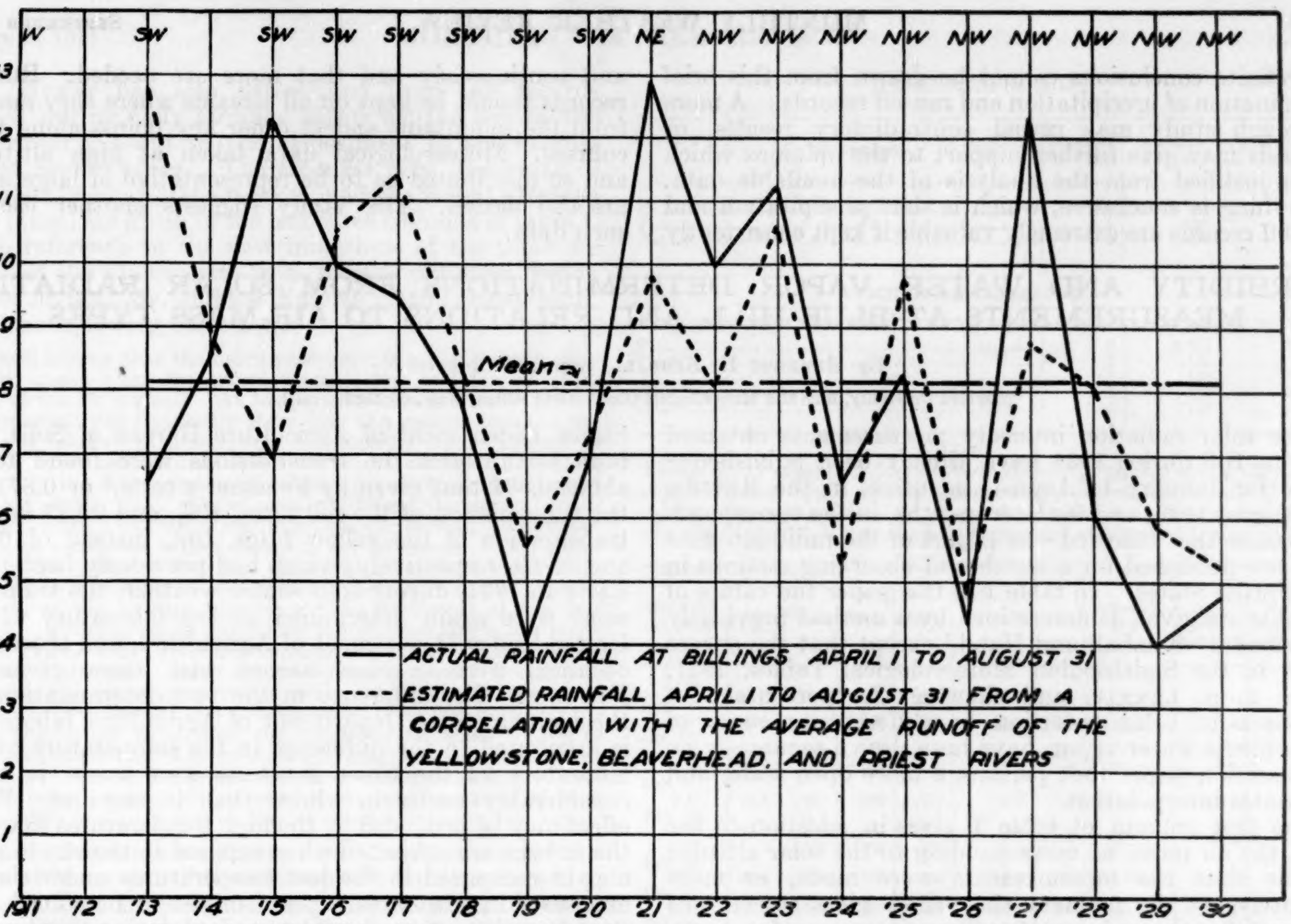


FIGURE 13.—Comparison of the actual rainfall at Billings with the amount estimated from a correlation with the average run-off of the Yellowstone, Beaverhead, and Priest Rivers.

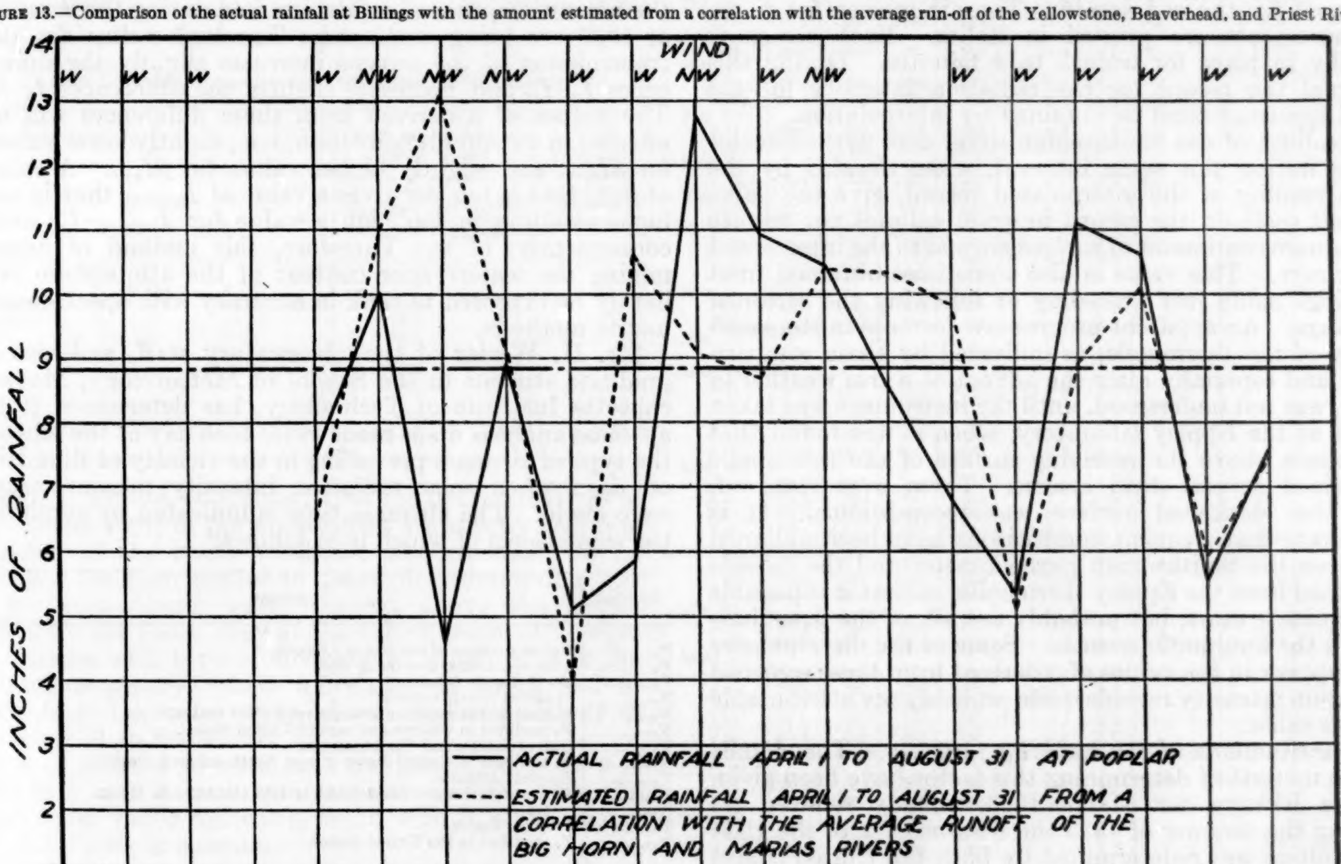


FIGURE 14.—Comparison of the actual rainfall at Poplar with the amount estimated from correlation with the average run-off of the Big Horn and Marias Rivers.

Definite conclusions cannot be drawn from this brief examination of precipitation and run-off records. A more thorough study may reveal contradictory results, or again it may give further support to the opinions which seem justified from the analysis of the available data. One thing is conclusive, which is that precipitation and run-off records are extremely valuable if kept consistently and continuously and that more are needed. Run-off records should be kept on all streams where they emerge from the mountains and at other key points along their courses. Meteorological data taken at high altitudes and so distributed as to be representative of large areas are also needed. This study suggests another use for such data.

TURBIDITY AND WATER VAPOR DETERMINATIONS FROM SOLAR RADIATION MEASUREMENTS AT BLUE HILL, AND RELATIONS TO AIR-MASS TYPES

By HERBERT H. KIMBALL, Research Observer

[Harvard University, Blue Hill Meteorological Observatory, Milton, Mass., September 1934]

The solar radiation intensity measurements obtained at Blue Hill during 1933 have already been published—those for January to August, inclusive, in the REVIEW for August 1933; and for later months, in the corresponding issues that followed—as a part of the radiation data that are published for a number of observing stations in the United States. In table 1 of this paper the values of β and w are given as determined by a method previously described by Kimball and Hand,[1] except that the curves given in the Smithsonian Meteorological Tables, 1931, figure 1, p. LXXXIV, and showing the percentage of depletion of solar radiation by different amounts of atmospheric water vapor, have been drawn separately on cross-section paper that permits a more open scale, and facilitates interpolation.

The first column of table 1 gives in addition to the date, the air mass, m, corresponding to the solar altitude at the time the measurements were made, or more definitely, at the moment the yellow glass screen was replaced by the red screen. The air masses for p. m. measurements are printed in italics. Each screen is usually in place for from 3 to 4 minutes. During this interval the record for the radiation intensity for the total spectrum must be obtained by interpolation.

Readings of the Smithsonian silver disk pyrheliometer made during this same interval, when divided by the scale reading of the interpolated record, give the value of unit scale on the record in gram calories per minute per square centimeter of surface normal to the intercepted solar rays. This value is also sometimes obtained from readings made just preceding or following the screened readings. An apparent progressive decrease in the sensitivity of the thermopile, as indicated by these comparisons, and especially after the advent of warm weather in 1934, was not understood, until the instrument was taken apart at the Eppley laboratory, when it was found that the space above the receiving surface of the thermopile contained several dead insects. These were removed, and the blackened surface was reconditioned. It is fortunate that frequent comparisons have been obtained between the Smithsonian pyrheliometer and the records obtained from the Eppley thermopile, so that it is possible to eliminate most, but probably not all, of the irregularities in the automatic records. Some of the discrepancies that appear in the values of β derived from these screened radiation intensity records quite probably are attributable to this cause.

Determinations of the turbidity factor, β.—The details of the method of determining this factor have been given in the REVIEW for March 1933, already referred to. During the summer of 1933 the transmission of the glass color filters was redetermined by both the United States Bureau of Standards and the laboratory of the United States Department of Agriculture Bureau of Soils. In both laboratories the transmissions were found to be about 0.992 that given by Feussner's tests,[2] or 0.871 for the transmission of the red filter, RG_2, and 0.882 for the transmission of the yellow filter, OG_1, instead of 0.878 and 0.889, respectively, which had previously been used. Early in 1934, during cold winter weather, the transmissions were again determined at the laboratory of the United States Department of Agriculture, and the values obtained were in close accord with those given by Feussner. The difference in the two determinations at the United States Department of Agriculture laboratory is attributed to the difference in the temperature of the laboratory at the times the tests were made, it being considerably cooler in winter than in summer. What effect may be produced by the high temperatures to which the screens are subjected when exposed to the sun in summer as compared to the low temperatures under similar exposures in winter, is a problem yet to be solved. In the mean time, the values determined during the summer of 1933 are being employed. Too high values for the transmission of the screens increases slightly the differences I_m-I_r, and decreases slightly the differences I_y-I_r. The values of β derived from these differences will be affected in an opposite direction, i. e., slightly lower values for βI_{m-r}, and slightly higher values for βI_{y-r}. A value of β_{mean} that is too low gives a value of $I_{m(w=0)}$ that is too high, resulting in too high a value for $I_{m(w=0)}-I_m$, and, consequently, of w. Therefore, this method of determining the water-vapor content of the atmosphere can hardly be expected to rank in accuracy with spectrobolometric methods.

Mr. H. Wexler of the observatory staff, and also a graduate student in the School of Meteorology, Massachusetts Institute of Technology, has determined from air-mass analysis maps made twice each day at the school, the type of air-mass prevailing in the vicinity of Blue Hill on days when solar radiation intensity measurements were made. The air-mass type is indicated by symbols, the significance of which is as follows:[3]

Symbol	Source
P_A	Colder portions of the North Atlantic.
P_C	Alaska, Canada, and the Arctic.
P_P	North Pacific Ocean.
N_{PA}	Modified North Atlantic.
N_{PC}	P_C modified in southern and central United States.
N_{PP}	P_P modified in western and central United States.
T_G	Gulf of Mexico and Caribbean Sea.
N_{TG}	T_G modified in United States or over North Atlantic Ocean.
T_A	Tropical Atlantic.
N_{TA}	T_A modified in the United States or over the Atlantic Ocean.
N_{TM}	Do
T_P	Tropical Pacific.
N_{TP}	T_P modified in the United States.

[1] Kimball, Herbert H., and Hand, Irving F. The Use of Glass Color Screens in the Study of Atmospheric Depletion of Solar Radiation. MONTHLY WEATHER REVIEW, vol. 61, pp. 80-83, March 1933.

[2] Met. Zeit., 1932, Heft 6, S. 242-244.

[3] For a complete exposition of the significance of the different air-mass types see Willett, H.C., American Air Mass Properties, Papers on Physical Oceanography and Meteorology. Published by Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, vol. 2, no. 2, Cambridge, Mass., June 1933.

Mr. Wexler has also determined from the records obtained during daily airplane flights by the school, the liquid water content of the atmosphere to the heights attained by the plane. The air-mass type, the value of w obtained from airplane records, and the height attained by the plane, are given in the last three columns of table 1.

With reference to the determinations of the moisture content of the atmosphere from records obtained during airplane flights, Mr. Jerome Namias of the school staff, makes the following statement:

It is well known that the hair hygrograph is a particularly sluggish instrument when the temperature is low and the moisture content of the air is small. At temperatures lower than −20° C., the hygrograph will frequently show only the general trend of the changes in relative humidity. In the months from January to April the upper atmosphere over Boston is coldest. Therefore the errors in the measurement of relative humidity are greatest at this period of the year. Under such conditions the general tendency will probably be for the readings at upper levels in the atmosphere to be somewhat higher than the actual values. This statement is based upon the fact that the moisture content is generally highest in the lowest layers, where the temperature is also highest. Therefore, as the airplane climbs, the lag coefficient of the hair increases. Under average conditions the highest flights are made in an anticylone which generally consists of a polar, perhaps transitional polar, air mass. Such air masses are generally free of any appreciable cloudiness, and considerable subsidence is frequently indicated. The effect of this subsidence is, of course, to lower the relative humidities throughout the subsiding air mass. Thus as the plane climbs into this dryer air the hygrograph should show the decrease, but due to the large coefficient of lag at such low temperatures only the general tendency to decreasing values of relative humidity is shown and so the recorded values are too high.

In table 2 are given for each month the mean of the liquid water content of the atmosphere for days on which solar radiation intensity measurements were obtained at Blue Hill, omitting the months June to September, when no airplane flights are made.

TABLE 2.—*Mean liquid water content of the atmosphere*

	From solar radiation measurements		From airplane soundings, liquid water in millimeters
	Number of days	Liquid water in millimeters	
1933			
January	2	3.2	6.7
February	8	3.2	6.2
March	12	3.5	4.7
April	9	6.7	9.2
May	11	16.2	13.6
October	16	12.8	15.8
November	15	9.9	10.0
December	3	13.3	11.0
Averages, May–November	-------	13.0	13.1

While it cannot be claimed that the determinations of the water content of the atmosphere are strictly accurate by either of the above methods, and especially as no correction has been applied to the airplane determinations for the atmospheric water content above the height reached by the plane, they at least show seasonal changes and changes with type of air-mass, as is indicated in the following summary, where midwinter is considered to extend from December 22 to March 21, and midsummer from June 21 to September 22.

It is of interest to note that the lowest value of β is found in P_c air in both summer and winter. Also, the lowest water-vapor content is found with P_c air in winter and with P_A air in summer.

MIDWINTER SEASON

Air mass source	Number of days	Average β mean	Average w (mm.)
P_C	5	0.044	2.0
P_A	1	.039	5.3
N_{PP}	5	.072	4.8

MIDSUMMER SEASON

Air mass source	Number of days	Average β mean	Average w (mm.)
P_C	6	0.043	21.4
P_A	1	.123	8.7
T_M	1	.143	15.0
N_{PA}	2	.085	21.0
N_{PP}	2	.056	10.8

TABLE 1.—*Values of β (atmospheric turbidity factor), and w (atmospheric water vapor content), computed from measurements of the total (I_m) and screened (I_y, I_r) solar radiation intensity, obtained at the Blue Hill Meteorological Observatory of Harvard University*

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w=0}-I_m$	w	Air-mass type	w, in mm., from airplane	Height of ascent, in meters
1933									
Jan. 15:						*mm*			
3.20	51.8	0.050	0.074	0.062	10.4	5.9	N_{PP}	8.1	4,920
Jan. 24:									
3.14	57.7	.063	.100	.082	.8	------	N_{PP}	5.3	5,300
2.09	71.7	.039	.052	.046	3.2	.6			
Feb. 6:									
2.45	73.0	.015	.022	.018	2.5	.5	P_C	2.3	4,900
Feb. 13:									
2.68	59.2	.048	.084	.066	6.6	2.0	N_{PC}	5.3	5,320
1.84	64.8	.075	.088	.082	5.3	1.7			
Feb. 16:									
3.08	55.4	.051	.080	.066	4.9	1.2	P_C, N_{PC}	3.7	5,230
Feb. 21:									
2.06	63.3	.063	.093	.078	4.6	1.3	N_{PP}	6.1	5,410
Feb. 22:									
1.93	67.2	.055	.053	.054	6.7	2.5	N_{PC}	5.4	5,130
Feb. 23:									
1.62	59.7	.099	.095	.097	10.0	9.0	N_{PP}	12.0	5,110
Feb. 24:									
1.86	59.8	.086	.080	.083	9.4	6.4	N_{PP}	6.1	5,310
2.56	57.1	.070	.078	.074	7.0	2.4	N_{PC}		
Feb. 27:									
1.57	70.2	.042	.026	.034	5.0	1.6	P_A	8.5	5,150
1.90	65.7	.049	.040	.044	10.2	9.0			
Mar. 5:									
1.55	74.6	.027	.067	.047	5.7	2.0	P_C	3.3	4,440
Mar. 6:									
2.72	63.7	.048	.051	.050	4.2	.9	P_C	3.9	5,080
1.76	71.1	.042	.055	.048	6.1	2.1			
1.50	73.1	.040	.062	.051	6.4	2.5			
1.49	73.2	.043	.047	.045	6.9	2.9			
1.57	71.2	.052	.082	.067	4.9	1.5			
Mar. 9:									
2.06	56.0	.096	.070	.083	10.2	8.8	N_{PP}	7.0	5,610
2.65	46.4	.091	.096	.094	11.9	13.8			
Mar. 10:									
2.18	62.1	.060	.065	.062	8.0	3.4	P_C	2.7	4,520
Mar. 11:									
2.31	69.2	.027	.070	.048	4.3	1.1	P_C	2.2	5,340
1.69	71.3	.033	.066	.050	2.7	.6			
1.55	75.3	.027	.031	.029	7.2	3.1			
1.45	75.3	.028	.033	.030	7.7	3.8			
2.08	67.9	.025	.061	.043	6.9	2.6			
Mar. 16:									
2.28	67.0	.036	.054	.045	6.0	1.9	P_C, N_{PC}	4.8	5,240
1.95	71.1	.039	.042	.040	5.7	1.8			
1.61	74.3	.046	.035	.040	5.6	1.9			
1.45	74.5	.054	.055	.054	5.1	1.7			
1.39	76.5	.047	.044	.046	4.4	1.4			
1.45	76.3	.047	.037	.042	4.7	1.5			
1.88	70.3	.052	.028	.040	6.4	2.3			
3.14	58.0	.049	.036	.042	8.9	4.5			
Mar. 17:									
1.38	69.9	.058	.092	.075	7.4	3.6	N_{PP}	10.0	5,050
1.39	66.8	.072	.052	.062	8.8	5.8			
Mar. 24:									
1.60	65.2	.069	-------	.069	9.5	7.3	P_C	4.4	5,240
1.34	73.1	.060	.037	.048	7.9	4.3			
1.32	74.7	.046	.038	.042	7.3	3.6			
1.32	74.0	.057	.046	.052	6.4	2.7			
1.55	69.9	.069	.053	.061	6.1	3.0			
2.24	60.2	.079	.055	.067	7.9	3.3			
Mar. 25:									
1.33	74.0	.055	.079	.067	4.1	1.2	P_C	3.8	5,320
1.31	73.6	.059	.069	.064	5.2	1.6			
Mar. 27:									
1.84	63.4	.064	.088	.076	8.3	4.0	P_A	5.2	5,250
2.51	55.1	.078	.085	.082	7.5	2.8			

TABLE 1.—*Values of β (atmospheric turbidity factor), and w (atmospheric water vapor content), computed from measurements of the total (I_m) and screened (I_y, I_r) solar radiation intensity, obtained at the Blue Hill Meteorological Observatory of Harvard University*—Continued

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w-0}-I_m$	w	Air-mass type	w, in mm., from airplane	Height of ascent, in meters
1933									
Mar. 29:						mm			
1.31	64.5	.116	.138	.127	5.5	2.0	P_A	9.4	4,920
Mar. 30:									
1.38	73.5	.052	.046	.049	7.0	3.1	N_{PC}	4.6	5,450
1.28	74.4	.050	------	.050	8.1	3.9			
1.83	68.5	.044	.045	.044	8.6	4.4			
Apr. 5:									
1.67	64.9	.081	.081	.081	7.2	3.0	N_{PC}	8.2	5,400
1.43	70.8	.057	.093	.075	5.9	2.2			
1.27	75.0	.047	.090	.068	3.8	1.1			
1.25	75.0	.048	.098	.073	4.8	1.6			
1.87	66.9	.050	.049	.050	8.3	4.0			
3.51	54.8	.052	.054	.053	8.7	3.3			
Apr. 9:									
1.24	72.8	.053	.034	.044	11.3	20.0	N_{PC}	9.2	5,180
Apr. 10:									
1.43	70.4	.054	.038	.046	10.1	10.0	N_{PC}	10.5	5,300
1.27	71.7	.060	.030	.045	10.6	15.0			
1.84	72.7	.050	.038	.044	10.1	12.0			
Apr. 11:									
1.62	68.5	.059	.032	.046	10.2	9.5	N_{PC}	11.5	5,320
Apr. 20:									
1.18	72.5	.069	.121	.095	3.6	.9	P_A	9.6	5,300
1.17	72.4	.074	.107	.090	5.3	1.7			
Apr. 21:									
1.81	65.5	.062	.093	.078	6.2	2.2	N_{PC}	8.2	5,460
1.73	68.2	.040	.070	.055	7.5	2.4			
1.23	70.8	.065	.140	.102	3.3	.8			
1.17	72.2	.071	.094	.082	5.8	2.0			
Apr. 22:									
1.58	72.1	.039	.078	.058	4.6	1.4	N_{PC}	9.9	4,700
Apr. 24:									
1.92	66.0	.049	.113	.081	3.0	.7	N_{PC}	10.1	6,100
1.19	67.8	.099	.073	.086	9.6	9.6			
1.15	68.9	.098	.123	.110	5.9	2.5			
2.20	49.1	.144	.124	.134	7.6	3.0			
Apr. 28:									
1.42	72.4	.047	.030	.038	10.6	13.0	N_{PC}	5.5	5,500
1.17	73.5	.070	.060	.065	7.3	3.9			
1.13	72.3	.074	.092	.083	6.3	2.8			
May 4:									
1.33	74.8	.039	.028	.034	8.8	6.5	N_{PC}	14.4	5,080
1.17	75.7	.040	.046	.043	8.1	5.0			
1.15	76.8	.031	.048	.040	7.8	4.7			
1.32	72.7	.043	.045	.044	9.1	7.3			
2.76	57.8	.063	.057	.060	7.2	3.0			
May 7:									
1.11	89.6	.019	.010	.014	8.7	7.5	N_{PC}	8.5	5,090
May 9:									
1.11	74.1	.063	.044	.054	8.7	5.0	P_C, T_G aloft	10.1	5,280
1.10	75.8	.052	.052	.052	6.4	3.0			
May 12:									
1.12	63.3	.128	.085	.106	12.6	37.0	N_{PC}, T_G aloft	20.4	5,290
1.74	44.6	.193	.160	.176	12.4	22.0			
May 15:									
1.13	71.2	.059	.062	.060	10.4	16.0	N_{PP}	12.2	5,940
May 16:									
1.45	69.2	.044	.034	.039	12.3	25.0	N_{PC}, T_G aloft	11.0	5,580
May 17:									
1.09	73.7	.053	.062	.058	9.1	9.1	N_{PC}	7.6	5,350
1.09	73.1	.056	.062	.059	9.5	11.0			
May 18:									
1.74	65.1	.064	.050	.057	9.8	10.0	N_{PC}	11.8	5,350
1.16	71.9	.084	.039	.062	9.1	8.3			
1.10	70.6	.086	.067	.076	9.3	9.7			
1.25	68.4	.076	.035	.056	12.6	33.0			
May 19:									
1.64	61.2	.082	.082	.082	10.7	12.0	N_{PA}	14.0	5,910
2.18	46.4	.106	.066	.086	18.1	------			
May 20:									
1.37	75.1	.026	.009	.018	10.9	15.0	T_G	18.0	5,710
May 24:									
1.57	56.6	.100	.098	.099	13.6	36.0	N_{PC}, T_G aloft	22.7	4,860

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w-0}-I_m$	w	Air mass type
1933							
June 2:						mm	
1.71	61.4	0.087	0.110	0.098	7.0	3.3	N_{PC}
1.06	77.0	.047	.024	.036	9.0	9.5	
1.18	76.3	.036	.021	.028	9.6	10.0	
1.71	68.6	.044	.034	.039	10.6	11.1	
June 3:							
2.93	51.2	.073	.070	.072	9.4	4.3	N_{PC}
1.27	63.7	.089	.085	.087	12.5	22.0	
1.09	67.6	.082	.089	.086	11.1	21.0	
1.19	64.3	.078	.040	.059	16.5	50.+	
June 4:							
1.22	65.9	.071	.081	.076	11.3	21.0	N_{PP}, N_{TM} aloft.
1.07	75.5	.026	.020	.023	11.2	25.0	
1.32	68.9	.051	.024	.038	14.2	48.0	
June 7:							
1.08	59.4	.146	.143	.144	13.0	42.2	N_{PC}, T_G aloft.

TABLE 1.—*Values of β (atmospheric turbidity factor), and w (atmospheric water vapor content), computed from measurements of the total (I_m) and screened (I_y, I_r) solar radiation intensity, obtained at the Blue Hill Meteorological Observatory of Harvard University*—Continued

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w-0}-I_m$	w	Air mass type
1933							
June 8:						mm	
1.23	63.0	.102	.070	.086	13.6	44.0	N_{PC}, T_G aloft.
1.14	62.7	.102	.083	.092	14.6	56.0	
1.07	64.4	.117	.089	.103	12.8	41.0	
1.06	64.4	.088	.074	.081	15.5	------	
June 9:							
1.36	61.3	.098	.078	.088	13.2	20.0	N_{PC}, T_G aloft.
1.11	64.6	.098	.087	.092	13.4	28.0	
1.06	65.6	.088	.071	.080	14.4	47.0	
1.32	53.6	.110	.108	.109	18.5	------	T_G
1.79	50.2	.124	.092	.108	16.0	27.0	
June 10:							
1.12	70.7	.054	.051	.052	12.2	27.0	N_{PC}
2.20	54.3	.072	.078	.075	13.0	17.6	T_G aloft.
June 11:							
2.42	50.3	.073	.085	.079	14.3	24.0	N_{PC}
1.45	64.3	.056	.081	.068	13.1	21.5	
1.13	71.0	.053	.051	.052	11.5	26.0	
1.06	71.9	.057	.064	.060	10.8	18.0	
1.10	71.7	.056	.071	.064	9.8	14.3	
1.40	67.5	.055	.059	.057	10.4	12.0	
1.43	67.2	.055	------	.055	11.1	16.0	
1.71	64.3	.055	.068	.062	10.3	13.0	
3.02	51.5	------	.059	.059	12.0	12.5	
June 12:							
1.06	61.6	.114	.083	.098	16.4	53.0	T_G
June 14:							
2.15	56.9	.077	.077	.077	9.4	5.6	P_C
1.41	64.9	.085	.087	.086	9.0	6.3	
1.17	63.9	.142	.112	.127	8.7	5.4	
June 15:							
2.64	56.2	.067	.056	.062	9.0	4.0	P_C
1.29	70.2	.060	.077	.068	8.3	4.9	
June 18:							
2.88	53.0	.060	.059	.060	10.7	8.0	P_C, N_{PC} aloft.
June 19:							
2.65	44.4	.116	.104	.110	11.6	12.4	P_C
June 20:							
1.07	71.8	.049	.059	.054	11.3	26.0	N_{PC}
1.06	74.6	.057	.067	.062	8.2	6.4	
1.06	72.1	.065	.066	.066	9.6	12.0	
June 22:							
1.19	62.5	.090	.114	.102	11.9	28.0	N_{PP}, N_{PC} aloft.
1.13	64.0	.091	.114	.102	12.2	33.0	
June 23:							
2.84	54.8	.059	.061	.060	9.2	4.1	N_{PP}
1.06	76.4	.041	------	.041	8.7	8.1	
1.08	76.1	.043	.018	.030	10.7	20.0	
1.11	75.6	.049	.062	.056	6.8	3.5	
1.84	64.6	.054	.045	.050	11.0	13.0	
2.99	56.8	.043	.016	.030	15.6	47.0	
June 24:							
2.70	57.8	.054	.039	.046	11.1	10.0	N_{PC}
1.26	65.0	.088	.077	.082	12.0	27.0	
1.06	64.1	.138	.128	.133	9.9	14.6	
1.76	55.4	.113	.128	.120	10.2	9.3	
June 27:							
1.64	51.3	.143	.143	.143	11.2	15.0	T_M
July 12:							
1.07	66.2	.145	.200	.172	3.2	.8	P_A
1.10	68.6	.143	.128	.136	4.1	1.3	
1.17	66.2	.133	.127	.130	6.2	2.9	
1.67	58.7	.089	.081	.085	12.3	22.0	
1.84	55.6	.106	.074	.090	12.7	24.0	
2.62	47.9	.104	.142	.123	5.1	1.3	
July 13:							
1.68	53.5	.155	.104	.130	9.9	8.3	N_{PA}
1.40	62.2	.086	.127	.106	9.1	6.7	
1.14	66.8	.084	.135	.110	8.2	5.5	
1.06	67.9	.099	.112	.106	9.1	9.5	
1.09	64.6	.105	.102	.104	12.0	30.2	
1.20	62.8	.095	.094	.094	13.8	47.0	
1.57	59.2	.085	.069	.077	14.4	46.0	
2.69	52.8	.049	.067	.058	13.4	22.0	
July 14:							
1.52	62.9	.076	.072	.074	11.9	20.0	N_{PA}
1.36	64.0	.084	.080	.082	11.7	21.0	
1.13	68.0	.079	.085	.082	10.6	18.0	
1.07	69.9	.071	.046	.058	11.9	32.0	
1.13	70.2	.076	.079	.078	9.2	9.0	
1.17	69.3	.062	.081	.072	10.8	9.9	
1.67	61.9	.076	.069	.072	11.6	25.0	
2.72	51.2	.072	.065	.068	12.8	26.0	
July 18:							
1.30	67.2	.071	.054	.062	12.3	29.0	N_{PC}
1.20	68.4	.072	.040	.056	13.0	38.6	
1.07	72.7	.046	.008	.027	14.4	57.0	
1.58	64.4	.050	.013	.032	17.2	------	
Aug. 6:							
1.12	76.8	.034	.031	.032	9.2	10.0	P_C
1.19	77.0	.025	------	.025	9.4	9.9	
1.34	73.2	.029	.012	.020	12.6	26.0	
1.53	69.4	.039	.022	.030	13.5	35.5	
Aug. 7:							
1.19	70.9	.049	.032	.040	13.0	39.0	N_{PC}
Aug. 9:							
1.13	72.5	.048	------	.048	10.8	19.3	P_C
1.18	72.3	.048	------	.048	9.2	16.0	
4.22	43.5	.050	.047	.048	15.5	32.0	

TABLE 1.—*Values of β (atmospheric turbidity factor), and w (atmospheric water vapor content), computed from measurements of the total (I_m) and screened (I_y, I_r) solar radiation intensity, obtained at the Blue Hill Meteorological Observatory of Harvard University*—Continued

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w-0}-I_m$	w	Air mass type
1933							
Aug. 11:						*mm*	
1.12	70.6	0.049	0.019	0.034	13.1	43.0	P_C, T_M aloft.
Aug. 26:							
3.10	56.3	.026	.029	.028	14.9	30.5	N_{PC}
3.63	46.3	.040	.025	.032	11.3	11.0	P_A
Aug. 27:							
1.26	56.1	.142	.109	.126	14.9	50	N_{PC}
1.58	58.0	.108	.075	.092	13.2	32.0	
Aug. 30:							
2.02	68.5	.031	.026	.029	10.1	7.7	P_C
1.19	72.8	.046	.056	.051	9.3	14.0	
1.24	72.6	.033	------	.033	11.8	25.0	
1.63	68.2	.036	.020	.028	13.9	39.0	
2.15	61.5	.042	.032	.037	14.0	46.0	
Sept. 2:							
1.73	59.9	.080	.061	.070	13.1	29.0	P_C
1.65	62.2	.074	.047	.060	13.5	33.0	
1.27	65.9	.081	.053	.067	14.1	43.0	
1.21	63.3	.110	.107	.108	10.2	13.0	
1.71	56.8	.106	.100	.103	11.0	13.0	
3.14	37.8	.114	.083	.098	15.8	50.0	
Sept. 12:							
2.19	68.4	.037	.019	.028	9.2	4.9	P_C
1.73	70.9	.044	.021	.032	9.4	6.3	
1.27	75.4	.041	.030	.036	8.2	4.8	
1.38	72.2	.050	.027	.038	10.4	12.0	
Sept. 13:							
1.34	73.1	.028	.025	.026	11.7	22.0	P_C
Sept. 19:							
2.81	53.8	.064	.065	.064	10.1	4.0	N_{PP}
Sept. 22:							
2.86	55.1	.044	.048	.046	12.6	18.1	P_C N_{PP} aloft.
Sept. 23:							
2.77	60.3	.045	.031	.038	10.3	8.2	P_C N_{PP} aloft.
1.45	73.0	.038	------	.038	8.7	5.2	
Sept. 30:							
1.74	65.3	.046	.030	.038	13.6	34.0	N_{PP}
1.45	64.4	.077	.051	.064	12.9	31.0	
1.45	66.9	.045	.056	.050	12.2	24.0	
2.02	58.4	.056	------	.056	14.0	36.0	

Date and air mass	$\frac{I_m}{1.94}$	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$I_{w-0}-I_m$	w	Air-mass type	w, in mm., from airplane	Height of ascent, in meters
1933									
Oct. 2:						*mm*			
1.72	59.8	0.079	0.069	0.074	12.5	23.0	N_{PP}	25.6	4.840
3.11	51.6	.045	.045	.045	14.6	42.0			
Oct. 3:									
1.99	62.4	.075	.075	.075	7.0	2.7	N_{PC}	15.9	5.280
1.52	69.1	.040	------	.040	7.4	3.3			
1.46	69.6	.041	------	.041	9.2	6.8			
Oct. 8:									
3.14	66.1	.004	------	.004	12.5	14.5	N_{PC}	26.1	5.180
1.57	71.2	.030	.004	.017	13.3	33.0			
1.50	70.6	.023	------	.023	13.3	35.0			
1.89	67.1	.027	.021	.024	13.7	33.0			
2.12	63.5	.033	------	.033	13.5	29.0			
Oct. 10:									
2.06	61.8	.074	.051	.062	8.2	3.7	N_{PC}	16.3	5.280
1.61	66.1	.070	------	.070	8.2	4.1			
1.53	66.4	.077	.054	.066	8.0	4.0			
2.26	53.9	.083	.065	.074	12.8	21.0			
Oct. 11:									
2.09	63.7	.056	.045	.050	9.3	5.4	N_{PC}	16.3	5.100
Oct. 12:									
2.13	55.7	.081	.082	.082	13.5	29.0	N_{PC}	23.1	5.180
2.21	46.7	.106	------	.106	14.3	36.7			
Oct. 14:									
2.16	64.8	.050	.025	.038	8.8	4.3	P_C	8.5	5,240
1.58	72.4	.025	------	.025	10.6	12.0			
1.63	71.5	.030	------	.030	10.1	9.3			
2.06	69.4	.028	.029	.028	9.1	4.9			
Oct. 15:									
2.06	66.2	.043	.011	.027	8.3	4.8			
1.58	69.9	.039	.030	.034	11.3	14.0	N_{PC}	14.7	5,180
1.72	67.4	.049	.021	.035	13.6	34.1	N_{PP}		
2.28	61.0	.039	------	.039	13.0	22.5			
Oct. 16:									
1.67	70.3	.037	------	.037	7.0	3.2	N_{PC}	15.9	5,370
1933									
Oct. 18:						*mm*			
2.15	62.5	0.058	0.043	0.050	9.9	7.2	N_{PP}	10.9	5,460
1.67	61.8	.084	.067	.076	10.6	11.0			
1.62	64.5	.079	.058	.068	10.1	5.7			
Oct. 19:									
2.28	66.7	.039	.031	.035	7.8	4.2	N_{PP}	9.8	5,140
1.70	71.8	.027	.047	.038	7.6	3.4			
1.78	70.4	.040	.024	.032	9.6	7.2			
Oct. 21:									
2.18	64.3	.054	.050	.052	7.7	3.0	P_C	14.8	5,540
Oct. 26:									
2.35	65.7	.043	.022	.032	9.6	5.4	P_C	9.3	5,360
1.89	70.3	.037	.034	.036	8.8	4.9			
1.74	72.1	.042	.037	.040	6.4	2.4			
2.61	61.8	.039	.049	.044	8.2	4.1			
Oct. 29:									
2.38	68.6	.039	------	.039	4.7	1.2	P_C	11.1	5,270
1.75	69.2	.037	.028	.032	3.8	1.0	N_{PP} aloft.		
Oct. 30:									
2.45	53.0	.088	.088	.088	8.7	3.9	P_C	12.8	5,320
1.90	59.7	.062	.067	.064	12.8	24.0	N_{PP} aloft.		
Oct. 30:									
1.90	46.7	.138	.140	.139	13.2	28.0	N_{PC} N_{PP} aloft.	22.4	4,620
Nov. 1:									
2.40	60.9	.055	.030	.042	11.6	14.0	N_{PC}	15.2	5,380
1.82	65.1	.045	------	.045	11.8	12.6			
1.95	65.3	.041	.035	.038	10.4	10.5			
2.53	62.4	.034	.020	.027	13.0	20.0			
2.88	59.4	.037	.022	.030	12.8	17.0			
Nov. 2:									
2.41	54.0	.075	.060	.068	12.5	18.0	N_{PC}	18.0	5,310
2.14	55.9	.079	.072	.076	11.6	15.0			
Nov. 5:									
1.88	70.4	.042	------	.042	6.6	2.4	P_C	5.7	4,080
Nov. 8:									
3.99	48.9	.068	.034	.051	11.7	11.0	P_C N_{PC} aloft	11.0	4,300
Nov. 11:									
2.17	65.7	.047	.040	.044	8.1	3.5	P_C	5.2	5,380
Nov. 12:									
2.00	60.4	.095	.088	.092	5.4	1.7	P_C	9.6	4,900
2.85	62.3	.049	.040	.044	6.2	2.2			
3.10	61.6	.039	.023	.031	8.6	3.4			
Nov. 16:									
2.33	71.5	.036	.027	.032	4.0	.9	P_C	1.7	4,850
2.06	71.2	.039	.016	.028	7.2	2.8			
3.70	58.3	.039	.027	.033	7.9	3.0			
Nov. 19:									
3.57	51.5	.055	.045	.050	10.3	5.0	P_C N_{PP} aloft.	5.3	4,080
Nov. 21:									
2.96	63.8	.015	.016	.016	12.8	17.0	P_C N_{PP} aloft.	10.5	5,050
Nov. 23:									
2.42	55.6	.068	.060	.064	12.2	17.0	P_C N_{PP} aloft.	10.7	4,880
Nov. 25:									
2.33	62.8	.042	.031	.036	11.7	15.0	P_C	9.1	4,740
Nov. 27:									
2.28	54.6	.083	.092	.088	9.4	5.2	N_{PP} aloft.	1.0	2,920
Nov. 28:									
2.84	49.0	.084	.080	.082	10.7	9.2	N_{PP}	7.7	4,870
Nov. 29:									
2.26	60.9	.053	.031	.042	13.1	24.0	N_{PP}	12.3	4,880
Nov. 30:									
2.81	39.7	.143	.147	.145	8.7	3.6	T_G	18.6	5,050
2.27	40.5	.160	.181	.170	10.1	7.8			
Dec. 7:									
2.46	61.2	.054	.054	.054	8.2	3.4	N_{PC}	8.9	4,740
2.41	60.5	.047	.063	.055	8.5	3.7			
Dec. 14:									
2.74	51.2	.070	.065	.068	12.3	15.0	P_C	5.5	4,800
3.97	42.0	.060	.074	.067	12.9	13.0	N_{PC} aloft.		
Dec. 16:									
2.62	56.6	.051	.035	.043	13.6	25.0	N_{PP}	18.7	4,180
3.63	45.4	.057	.055	.056	14.1	22.0			
Dec. 28:									
3.86	50.1	.062	.057	.060	7.3	2.0	N_{PC}	------	------

ESTIMATING THE YIELD OF GRAIN FROM THE WEATHER

By A. H. BOGUE

[Dominion Bureau of Statistics, Ottawa, August 1934]

"Weather", state J. B. Kincer and W. A. Mattice, of the Weather Bureau at Washington, in their Statistical Correlations of Weather Influence upon Crop Yields, "in the aggregate, for a given period of time as affecting plant growth, is a composite of many elements, such as temperature, rainfall, sunshine, wind, relative humidity, etc. Growing crops are influenced more or less by all these which, in combination with one another, make up the weather of the season." It is realized that there are limitations to the study of the influence of weather upon the growth and development of the wheat plant and other grains and finally the yield. This is owing to the fact that there is a large number of phases to each of the above elements. For temperature, for instance, there are the mean daily maximum, mean daily minimum, highest temperature, mean daily range, etc. Rainfall can likewise be subdivided into many phases. It is the writer's intention to confine himself principally to the total provincial monthly rainfall (average for a number of stations) and the mean daily minimum and maximum temperatures (average for the province).

Some investigators of this problem.—Among those outstanding agriculturists who have attempted to relate the yield of grain crops to the weather are Gilbert and Lawes, of the Rothamsted Experiment Station at Harpenden, England. Dr. E. H. Chapman, formerly of the Dominion Bureau of Statistics, himself a student of the subject, stated in his Forecasting of Crops from the Weather that in 1880 Gilbert and Lawes came to the conclusion that seasons of high production were preceded by a warm winter, a warm early spring, and a shortage of rain in winter and spring. As far as Canada is concerned this might apply to fall wheat and rye but not to spring crops with which we are dealing in this article. He also stated that Sir Napier Shaw, the eminent English meteorologist, in 1905 endeavored to calculate the yield of wheat in England, basing his estimates upon the rain of the previous autumn. Later, S. M. Jacob, of the Indian Meteorological Service, in a paper published in 1916, showed how in India even well-irrigated wheat liked a moist seed bed in September. In Japan, work has been done in forecasting the yield of rice. "It has been observed" stated Dr. Chapman, "that the success of the rice crop depended chiefly upon an even temperature and bright sunshine in August, cold at that season involving a failure." In Sweden, Alex Wallen found that there was a distinct relationship between rainfall and temperature on the the one hand, and the yield of the four cereals, wheat, barley, oats, and rye, for each of the 26 governments of Sweden in every month of the growing periods of these crops during 1881–1910, the period of his study. Then we have A. J. Connor, climatologist of the Dominion Meteorological Office at Toronto, who has made important contributions in the field of agricultural meteorology. The work of T. R. Blair in the United States should also be mentioned.[1]

Previous work on this problem.—In commencing this study the records of the different experiment stations in the West were examined. A series of charts were drawn, showing the inches of rain for the months of April to September; the minimum, the maximum and mean temperature; and also the hours of sunshine, for each year of the period 1918–27. The condition of the wheat crop as given by crop correspondents of the Dominion Bureau of Statistics at May 31, June 30, July 31, for each of these years was compared with the amount of rainfall and the temperatures for each month, and there was observed a relationship between the yield (as derived from the condition reports) and the variations in these two factors. In general, a favorable distribution of rain and even temperatures resulted in average or better yields, and this result was confirmed when the actual yield was forecast later in the season by crop conditions and threshing returns, other than the method we are about to describe. From this start, it was decided to select from the various records of meteorological data, those bearing most directly upon crop yields, such as we have already mentioned. In carrying out this idea, an experiment was made with the 1926 census of the Prairie Provinces, which dealt with the yields of crops for the year 1925.

The 1926 census of agriculture used as a basis of this study.—In this experiment, 50 areas lying close to as many meteorological stations in Saskatchewan were chosen. These areas were selected as representative localities in the Wheat Belt of this Province, as follows: *Qu'Appelle River region:* Arcola, Caron, Drinkwater, Imperial, Kamsack, Lunsden, Nokomis, Pilger, Qu'Appelle, Quill Lake, Seamans, Strasbourg, Whitewood, Yellow Grass, Yorkton. *South Saskatchewan region:* Assiniboia, Cadillac, Chaplin, Coulee, Consul, Gravelbourg, Haverhill, Hughton, Klintonel, Leader, Maple Creek, Outlook, Penant, Shaunavon, Swift Current, Vidora. *North Saskatchewan region:* Anglia, Biggar, Kindersley, Macklin, Meadow Lake, Prince, St. Walburg, Scott, Turtleford, Waweca, Witchekan. *Saskatchewan Forks region:* Dundurn, Harris, Kinistine, Melfort, Prince Albert, Rosthern, Saskatoon, Tugaske. These stations are selected from the four geographical regions of the Province. They were taken to represent the different climatic conditions, types of soil, etc. of the wheat region. The yield per acre of spring wheat for the year 1925 in each of these areas, or parts of census divisions, was calculated from the records of the census. These yields were then studied in connection with the total monthly rainfall, mean daily range of temperature, mean monthly temperature for each of the above stations and for each of the months April to September during 1925. An endeavor was made to discover, if possible, whether there was any relationship between the yield of wheat in each area with the rainfall in each month; that is, whether variations in the number of inches of rainfall corresponded with any differences in yield per bushel of spring wheat from one area to another. Besides these weather factors, other data contained in the census records, such as rural population per 1,000 acres, acreage of unimproved and improved land, percentage of land owned or rented, acreage under summer-fallow, spring and fall plowing, yearly expenditure upon equipment, etc., were studied as to their possible influence upon the yield of spring wheat. But it was found that these factors, other than those of the weather, could not be used in their available forms as having any direct bearing upon the yield, due probably to the presence of other unknown compensating factors whose effects could not be estimated.

[1] Thomas R. Blair. Partial correlation applied to Dakota data on weather and wheat yield, Mo. WEA. REV., February, 1918, 46: 71–73. Temperature and spring wheat in the Dakotas, *ibid.*, January, 1915, 43: 24–26.

Variations in yield.—We discovered a wide variation in the yield per acre of spring wheat in these different areas. Our method has been to place the yield and the rainfall for each area and station alongside one another and to study the bearing which one has on the other, or whether a large plus or minus from the average difference in rainfall from one station to another is accompanied by a similar change in yield in the area contiguous to that station. If a definite relationship could be established between these two variables and other weather factors, and mathematically expressed, it would be quite possible to estimate the probable yield for subsequent years from the experience of the year we are studying. The difficulty, however, is in the wide variation in the amounts of rain which fall at each point in any month. By taking a period of years rather than a single year such as we already have done, seasonable differences are largely overcome by counterbalancing the effect of one season upon another.

Results of the study of the 1925 census.—For the purpose of preventing the accidental features of a single year which might occur, such as hail, early frost damage, insect injury, from in some measure hiding the results we have been trying to obtain, the average yield per acre of spring wheat for each of the above areas for the years immediately surrounding 1925, viz, 1923, 1924, 1926 and 1927, were also compared with the yields in each area for 1925 and with the meteorological data already mentioned. By suitable methods, a fairly high "total correlation" was obtained. This correlation seemed sufficiently high to warrant the belief that certain of the data could be used as a means of estimating the crop; its value was $R=0.80$, demonstrating the fact that, for the year 1925 in Saskatchewan at least, these various factors were closely related to yield. This, however, might not always be the case. For instance, if we had been enabled to gather data about the peculiarities of each area, that is, for instance, the average rainfall distribution for each month of past years, and the variations from the normal temperature, we might find that in some years the yield showed little relationship to the weather, due to the interference of other agencies such as hail, rust, early frost, etc. This coefficient, although amply sufficient to demonstrate the correlation between yield and the previously mentioned weather factors, was not considered of sufficiently high value to warrant its reliability for prediction. The next step, therefore, was to collect the data on yield and weather for a period of years to determine whether this method would give a higher relationship and be a surer means of estimating the yield from the weather data available.

Study of the period 1904–28 in Saskatchewan.—The differences from the average, or the variability in the crop yields already referred to, due to nature of soil, etc., which might be considered as existing between 50 areas would largely disappear when the Province as a whole was taken over a series of years. Changes in methods of culture, and different crop rotations, in the Province over this period would be slow; increases in yield due to improved methods of culture in some parts of the Province would be largely counterbalanced by the exhaustion of soil in other parts. To demonstrate the differences in yield (average for the whole Province), from one year to another and in the amounts of rainfall in comparison with a single year at different points, table 1 has been constructed:

TABLE 1.—*Yield per acre of spring wheat in Saskatchewan compared with rainfall of the growing period (April to July) for the years 1904–30*

Year	Yield per acre	Rainfall, April-July	Year	Yield per acre	Rainfall, April-July
	Bushels	*Inches*		*Bushels*	*Inches*
1904	17.5	6.43	1919	8.5	5.81
1905	22.3	7.67	1920	11.2	6.71
1906	21.4	9.55	1921	13.7	10.36
1907	13.5	7.10	1922	20.2	6.92
1908	13.6	8.08	1923	21.2	11.19
1909	22.1	11.15	1924	10.2	5.13
1910	15.5	6.75	1925	18.8	7.72
1911	18.5	10.24	1926	16.2	6.33
1912	19.9	9.46	1927	19.5	10.49
1913	19.5	7.32	1928	23.3	6.71
1914	12.4	6.17	1929	11.1	4.95
1915	25.2	8.97	1930	13.7	6.89
1916	14.2	11.07			
1917	14.2	4.74	Average 1904–30	16.6	7.78
1918	10.0	5.92			

An inspection of the above table shows that the variations in the yield of wheat and in the amount of rainfall for each of the years in question do not exactly coincide. For instance, in 1922 the yield per acre for the Province averaged 20.2 bushels and rainfall for the growing period over the Province 6.92 inches, while in the following season of 1923 the yield was 21.2 bushels per acre with a rainfall of 11.19 inches, which was well above average. It would be expected that a larger rainfall would produce a larger yield in 1923 than in 1922. We note from this table a number of seasons in which the rainfall was practically equal to the average of 7.78 inches, viz: 1905, 1913, 1925. But yields equal to, or nearly, the average of 16.6 bushels did not correspond with average rainfall. We do notice, however, that the years which had low rainfall, such as 1914, 1919, 1924, 1929, also had low yields, partly due to this fact along with other peculiar features of each season which we will refer to later and which make it difficult to secure a high relationship. Included in this study are the total monthly rainfall of the previous fall months of September and October, the total monthly rainfall for each of the current months of April to August, and the mean daily minimum temperature for the month of July. The total correlation (as explained before) between the yield of wheat for the preceding years and these meteorological data was $R=0.90$, higher than that obtained from a study of the yields and weather factors in the census year.

Study of the period 1914–28 for each of the three prairie Provinces of Canada.—The results of this second study, however, were not considered of sufficient value to warrant the making of an estimate. It became clear that the methods used in the collection of data between the years 1904–13 were different from those used after 1914 owing to an improvement in the manner of compilation by both the Provinces and the Dominion Bureau of Statistics. This was considered a strong disturbing element in obtaining satisfactory results from a study of the period 1914–28 either in Saskatchewan or the other two Provinces. In the study of yields, therefore, for the period 1914–28 in each of the three prairie Provinces, rainfall and temperature were studied in their relationship to one another. Included in this investigation were the previous autumn rainfall of the months August, September and October, the winter precipitation, (the months of November to March being included), the total monthly rainfall of the months of April to July, already studied in the former series, and the mean daily maximum temperature for July.

The rainfall of the above periods was found on analysis to vary directly with the yields when taken over the whole period. However, an increase in rainfall from one year to another did not always result in a corresponding increase in yield, but was often the reverse. Generally, however, yields over 15 bushels per acre, the average for the years 1914–28, accompanied average amounts of monthly rain of 4.0 or more inches in the previous fall, over 3 inches in June and in July. Exceptions from this, which occurred in our study, have been the reason for our taking up this work and making such a complete analysis of yields in each of the Provinces. With *regard to winter precipitation which has been included*, there was found to be a minus relationship between the yields of wheat in each of the Provinces under review and the amount of snowfall and rain during the winter months. This did not mean that the snowfall had no bearing or influence, but that its influence or effect was hidden by other factors, some of which have been referred to already. Experiments made at the experimental station at Swift Current, over a period of 7 years up to 1929, have discovered no appreciable increase in soil moisture from the snow cover of the previous winter. Whatever increase had taken place could be wholly ascribed to rains which penetrated the soil when the ground was in an unfrozen condition. Evidence to confirm this statement was available over an extensive area during the spring of 1928.

The results from our study for this period of 1914–28 of the yields of spring wheat in each of the three Prairie Provinces and the extent of its dependence upon the previous fall rain, previous winter precipitation, rainfall of growing months, and mean maximum temperature were considered quite satisfactory. Fairly high relationships were established when these factors were correlated with the average yields of spring wheat in each Province. The estimated yields obtained from this study were compared with the actual yields as compiled by the Bureau of Statistics and provincial governments. In many cases the expected yields were very close to the actual yields over this period, but for some of the years there was a difference due to causes in which the true relationship between the yield and rainfall could not be established owing to other factors or unknown agencies (or perhaps forces) being at work to offset the effect of the rainfall or beneficial temperature. A closer approximation between the estimated yield in Saskatchewan and the actual yield was secured than for the other two Provinces for the period of years used, although the variability or difference of the yields from the average was less in Manitoba than for either Saskatchewan or Alberta.

Additional meteorological factors.—Some of the forces which have rather counteracted the beneficial influence of rainfall or moderate temperatures during the growing period are soil drifting, insect damage, rust—these three take a large toll in some years, such as that by the rust epidemic in 1916. We have already referred to these factors as accidental features of a single year and for this reason we took a period of years for our study, and we have partly succeeded in overcoming this difficulty by obtaining a fairly high relationship or total correlation. Insect injury in a large measure is due to certain weather conditions. Soil blowing is partly due to dry weather and high winds. Rust is caused by wet weather and high temperatures and high humidity, besides the direction of certain winds which carry the rust spores. These, it has been thought, have been so intermixed with certain weather factors as to make it difficult to measure the degree of influence or "weight" exerted by the rainfall at any particular period.

Experimental farms of Canada.—Bearing in mind the importance of making a finer analysis of selected districts in each Province, similar to that of the 1926 census (only over a period of years), it was decided to make a study of the yields of not only spring wheat but also the other grains on the experimental farms. The nine farms and stations in western Canada included in this study are: Manitoba—Brandon and Morden; Saskatchewan—Indian Head, Rosthern, Melfort, and Swift Current; Alberta—Lethbridge, Lacombe, and Beaverlodge in the Peace River country. These stations were chosen not only for the reliability of their yield records but also for the reason of the rotation experiments on different ereael crops in connection with their response to certain environment, the combination of crops, fertilizing, and other cultural experiments. It is their response to environment with which we are concerned, as these are additional features in our study of the yield of cereal crops and the weather. This point has been investigated in our consideration of the yields of spring wheat at each of the 50 areas as influenced by fall plowing, spring plowing, summer-fallowing, etc. We were not able in our study of the census data, however, to establish any definite relationship between yield and these nonmeteorological factors. It is hoped in this study at each of the farms to find some connection between yield and the various methods of culture which can be reduced to a mathematical basis, such as we have endeavored to do in previous studies, in order to make an estimate of the yield.

A study is being made of the rainfall during the crop years at the experimental farms of Brandon, Manitoba; Indian Head and Scott, Saskatchewan; Lacombe, Lethbridge in Alberta, from the time these farms were started, up to the present time. The average maximum temperature for the current months of May, June, July will be related to the precipitation over each preceding crop year.

The "quotient" obtained by dividing the second factor by the first will be studied in relation to the yield of wheat and other crops. Mr. A. J. Connor, M. A., climatologist to the Dominion Meteorological Office at Toronto, has made a study of this, and very interesting results have been obtained by him for the districts surrounding the meteorological stations of Winnipeg, Calgary, Edmonton, Medicine Hat, Battleford, Prince Albert, Qu'Appelle, and Swift Current, in which records have been available since 1883. The "quotient" mentioned above has been compared to the periods in which minimum and maximum sun spots have occurred, and these again compared with the yields of spring wheat in the above areas. This study of additional stations will be especially valuable owing to the fact that severe droughts have occurred in the prairie Provinces during the last 4 years. (See Canada Year Book, 1933, pp. 47–59—Droughts in Western Canada, by A. J. Connor.)

A minute study of plant growth necessary.—In addition to studying yields in their relation to weather and other factors, already dealt with in detail, account must be taken of plant growth throughout the growing season. Its development must be carefully watched. Extensive soil-moisture experiments are being carried on at the Swift Current experimental station by Mr. S. Barnes, who is attached to the department of field husbandry of the experimental farms system. Much has been done to establish a relationship between the plant and factors connected with its growth. Evaporation is an important factor, in that the amount of water lost through this means might be greater than the amount of water received by the soil through rain, in which case a loss would occur in the available supply for the plant.

Evaporation.—By certain methods in use at the experiment stations the amount of water in the soil at seeding time is determined. At stated intervals the soil is weighed to determine the loss through evaporation. The difference between the initial and final weight each month indicates the water lost by the soil through evaporation and transpiration of the plants. It is stated that, as a rule, rainfall higher than average in dry climates results in yields higher than average, while in humid climates rainfall less than average usually produces yields higher than average. (Studies on yields and weather in other parts of Canada additional to that undertaken in the Prairie Provinces will be carried out in order to contrast the relationship in climates different from that of the west.) This might be partly due to less evaporation in humid climates; the supply of soil moisture thereby being more constant than in dry areas like that of southwestern Saskatchewan and in fact other parts of the prairies where the soil moisture is so rapidly depleted, and where abundant rains are at all times a necessity. Our study of the problem has convinced us that the rainfall is of prime importance. Unfortunately, however, data of sufficient amount to cover a great many more areas in the grain-growing regions of the west are not yet available.

Encouraging results, up to the present time, have been obtained and have led to the belief that the possibilities of estimating the yield of the various crops, based on the study of weather conditions of past periods, are very good. It will be quite possible, in fact, to make a prediction as to the outcome of the crop early in the season (in addition to the many reports on condition, based on averages) directly by taking the number of inches of rain at stated periods ("weighting" by proper methods) and from the above results making a calculation, in yield per acre, of the crop. Of course, the nonmeteorological agencies mentioned will be given consideration. The study of this problem, up to this point, has been the endeavor to establish some relationship between yield and weather, so that the various factors, principally rainfall and temperature, might be given certain values or weights in order to make, if possible, some calculation of the probable yield as compared with the actual yields reported by other methods now already established by the provincial governments, the Dominion Bureau of Statistics, and other agencies interested in the outcome of the crop, such as the grain exchange, the different wheat pools, Sanford Evans Statistical Agency, and the farming community in general.

Conclusion.—The important points which have been brought out in this article are, first, that rainfall, at certain periods of the year, is perhaps more important than at other times, depending on the crop that is grown. Our study has been on the yield of spring wheat in the prairie Provinces of Canada. Here we have investigated the yields both at several points in the Province of Saskatchewan for a particular year, namely, 1925, and over a period of years, namely, 1914–28, in each of the Provinces. We have brought out the fact that, of the two weather factors studied, rainfall and temperature, the first is the most influential. The way in which rainfall comes has a great deal to do with its usefulness. Showers during the growing period help the crop for a short time, but for storing water in the soil, showers of one-half inch or more are necessary. Then, the distribution of rainfall is very important. If the rainfall is of a torrential character, the rain falling at the rate of an inch or more per hour, the loss through run-off is serious. The summer-fallow is quite important and is partly for the purpose of controlling weeds and for storing moisture. Secondly, we have evaporation, which in many cases exceeds the amount of rainfall, so that the amount of soil moisture is lessened. Then, there are several other factors which are at work to reduce the yields besides lack of rainfall, such as lateness of seeding, poor cultural methods, poor seed, the wrong type of soil for a certain crop—although in this case well-distributed rainfall on comparatively poor soil might produce a good crop, while less than the average rainfall would result in a poor crop or none at all, as we have witnessed this past year in the West. Insect injury, plant diseases, and soil drifting are partly dependent upon moisture conditions as well as on temperature. It has been the endeavor of the writer to link up all these factors together over a period of years. The experience of past seasons has assisted in making some kind of a prediction of the crop. The successful solution of estimating yields, however, requires the cooperation of not only a specialist in statistics but also in agriculture and weather forecasting. It is planned to make an extended field study of crops over a period of years, and it is confidently hoped that a method will be found of accurately determining the yield of crops early in the season.

TIME LIMITS OF THE DAY AS AFFECTING RECORDS OF MINIMUM TEMPERATURE

By E. S. NICHOLS

[Weather Bureau office, Harlingen, Tex., July 1934]

Different methods of obtaining temperature records, especially variations in the time at which observations are taken, cause differences in the beginning and the end of the "day" for which temperature extremes are recorded. Thus, at regular Weather Bureau stations the daily maximum and minimum temperatures are recorded for the calendar day, midnight to midnight, local standard time, the data being taken from the station thermograms when the extremes are not shown by actual thermometer readings; while the recommended, though not universal, time for the once-daily observations at cooperative climatological stations is "about sunset"; and the maximum and minimum temperatures then read are recorded as belonging to the current day (on which they usually occur). At certain other stations, especially certain classes operated in some special services, as well as at some cooperative climatological stations, thermometers are read and set once daily in the morning, in many cases at 7 a. m. local time, or even earlier; and the minimum temperature then read is recorded as that of the current date, while the maximum-thermometer reading is, in published reports, set back to the preceding date, on which it almost always occurs. The early-morning readings are, at some stations, supplemented by additional afternoon settings of the minimum thermometer. Experience in different sections of the United States has shown that such differences in the periods taken as the "day" (even though each contains 24 hours) cause differences in the temperature records obtained; and questions arise regarding the frequency, amount, and importance of such variations in the records.

PREVIOUS INVESTIGATIONS

Hann and Süring in their "Lehrbuch" object to the use of the maximum-minimum thermometer, because of the ease with which the instrument becomes out of order and because of sunshine effects on the maximum reading, but is silent as to results of variation in the time of setting,[1] as are other writers generally. However, Ward in his translation of Hann's Handbuch der Klimatologie refers to a study of time-of-observation effects on the maximum, minimum, and mean temperatures at the Royal Observatory, Greenwich, during the years 1886-89, by Ellis.[2] Apparently the time of observation is not generally considered as of great importance.

DATA USED IN PRESENT INVESTIGATION

In the present paper certain phases of the subject are considered through examination of the minimum temperatures that occurred during portions of three frost seasons (cold portions of the year) in the Rio Grande fruit-frost district of south Texas, where requisite thermograph records have been obtained for a number of field stations. Three of these stations have been selected for study: Harlingen and Mission in the lower Rio Grande Valley (the former station relatively near the coast of the Gulf of Mexico and the latter about 39 miles west of Harlingen, in the interior) and Dilley, located in the "winter garden" section southwest of San Antonio. Approximate latitudes, longitudes, and variations of local mean solar time from central standard time (the standard in local use) are as follows, for the three chosen stations:

Stations	Latitudes (north)		Longitudes (west)		Time differences
	°	′	°	′	
Harlingen	26	12	97	42	31 minutes slower.
Mission	26	13	98	20	33 minutes slower.
Dilley	28	41	99	11	37 minutes slower.

DESCRIPTION OF TABLES

Taking the minimum temperature (to whole degrees Fahrenheit) for each 24-hour period ended at 6 p. m. as the standard and using thermograms corrected for available readings of the maximum and minimum thermometers, differences in the daily minimum temperatures resulting from considering the day as ending at 7 a. m., 8 a. m., and midnight, central standard time, have been determined separately for each of the three stations chosen, for December, 1931, 1932, and 1933, and for January, February, and March, of 1932, 1933, and 1934. We might have taken any other time than 6 p. m. as the preliminary standard, but this time is chosen for reasons that will appear later, as well as because it is "about sunset", which is, as already stated, the preferred time for cooperative climatological station observations. The minimum temperatures we use for each date are, of course, those that would have been obtained by once-daily settings of the minimum thermometer at each time of day specified.

In tables 1, 2, and 3, herewith, have been entered for Harlingen, Mission, and Dilley, respectively, for each of the 12 months listed above and for each of the four sets of 3 months of the same name comprising the 12, the numbers of cases, the totals, and the greatest of positive and of negative departures of the daily minimum temperatures from the 6 p. m. standard determined as above. By this method any date on which the minimum temperatures for the 6 p. m. and any other type of day are the same is not counted in that connection, since the departure is 0. Also, the totals of the absolute values of all the positive and the negative departures together and the averages thereof have been entered for each period, station, and type of day, as well as the resultant algebraic sums and the average daily amounts of such resultants (sums divided by number of days in periods). The latter averages, therefore, give the amounts by which the respective monthly mean minimum temperatures are affected by the variations in the "day" used. Finally, at the bottom of each table are given, for each type of day, the total number of negative, the total number of positive, and the total number of all departures, together with the percentage frequencies of the grand totals; i. e., 100 times the grand totals (of frequencies) divided by 364 (the number of days in our 12-month period).

In the second portion of each table are entered, for each type of day, the number of times minimum temperatures of 40° or lower, 32°, 25°, and 20°, or lower occurred in each monthly or trimonthly period, while at the bottom of this portion are given the total number of times each low-temperature group occurred, together with the percentage changes (increases in all cases) from the number of times of occurrence during the 6 p. m.-ending days.

WHAT THE DATA SHOW

While frequencies of low temperatures at Dilley, as shown by the second parts of tables 1, 2, and 3, are considerably greater and the mean minimum temperatures there (as shown by published climatological reports) are several degrees lower than corresponding data for the other two stations we are using, the frequencies, averages, and extremes of departures and the relative (percentage) variations in frequencies of low temperatures for the three places do not differ greatly. Frequencies of departures of whichever sign for the 7 a. m.-ending days for the entire 12 months are nearly or quite 50 percent; that is, about *one-half* of the daily minima differ from those for the corresponding 6 p. m.-ending days. Departure frequencies decrease to slightly more than one-third of all cases when 8 a. m., instead of 7 a. m., minima are used; and to about one-fourth or one-fifth when we use midnight-to-midnight minima. Negative departures are several times as frequent as positives in the 7 a. m. data; and, while the relative excess of negatives decreases at 8 a. m. and still more when we take the midnight cases, negatives continue the more frequent during all these types of day.

Occasional cases of departures of nearly or quite 20°, and even more in a few cases, both positive and negative are scattered through our tables, least frequently in the midnight columns. Trimonthly averages of all departures during 7 a. m.-ending data are mostly about 5° or 6°; they are usually less for the other types, being about 4° for midnight. In general the negative departures make greater monthly totals than the positive, so that resultant departures and daily averages thereof are mostly negative; these averages mostly fall within the limits −1.5° and −2.5° for the 7 a. m. days (all averages being negative at this time); −0.8 to −1.5° for the 8

[1] Lehrbuch der Meteorologie, fourth edition, p. 95.

[2] Handbook of Climatology, by Julius Hann, translated by R. DeC. Ward, p. 8, refers to "On the Difference Produced in the Mean Temperature Derived from Daily Maxima and Minima as Dependent on the Time at which the Thermometers are Read", by W. Ellis, in Quart. Jour. Roy. Met. Soc., XVI, 1890, 213-218.

a. m. days, though 3 or 4 slight positive averages were found; and from $-0.5°$ to $-1.0°$ for midnight, all of these averages being negative though one is as small as $-0.1°$.

CAUSES OF DIFFERENCES

Even a cursory examination of the individual records shows that the most of the negative differences for 7 and 8 a. m. are due to the fact that the current temperatures (temperatures at which thermometers are set if observations be taken then) at those times are often lower than the temperature at any time during the ensuing night; that many of the negative departures for the midnight-ending days are due to the fall of temperature between 6 p. m. and midnight to points lower than the minima of the immediately preceding nights. On the other hand, many of the 7 and 8 a. m. positive departures are due to the fall of temperature during the remainder of the forenoon and the afternoon up to 6 p. m. to points lower than the minimum of the preceding night and early morning; and that some of the positive departures for midnight-ending days are due to the occurrence of nocturnal minima previous to midnight. (Numerous thermograms might be given to illustrate these conditions.) There remain fortuitous differences that are due mainly to the onset of, and recovery from, cold waves, and that are to a considerable extent independent of our time limits.

ADDITIONAL TIMES CONSIDERED

Because of the above-mentioned causes of negative departures when our "day" ends during the early morning hours, data similar to those of tables 1, 2, and 3 have been prepared for days ending at 9 and 10 a. m., noon, and 3 p. m., using the same thermograms as were used in preparing the Harlingen table 1. These new data appear in table 4, herewith. It appears from the preceding discussion that data for the other two stations previously used would not show essentially different results. Further decreases in the total numbers of positive and of negative differences are shown for progressively later hours, especially between 8 a. m. and 9 a. m., less between 9 and 10 a. m., and still less between 10 a. m. and noon. Noon and 3 p. m. frequencies do not differ greatly, and they are relatively low, being only 7 and 5 percent, respectively. Ten a. m. has only 10 percent. From 10 a. m. onward to 3 p. m., frequencies and totals of positive exceed those of negative differences; and resultant averages are, therefore, positive though amounting to only from one- to four-tenths of a degree. Extreme differences have decreased, positives seldom reaching 10° at noon or more than 5° at 3 p. m., while extreme minima have fallen to about 5° in the 10 a. m. columns to 1° or 2° in the noon, and to 1° or 0° in the 3 p. m. lists. Averages of all positive and negative differences hold up well until 10 a. m., when they are about 5°; a fall to about 4° occurs at noon, and a further drop to about 3° is found for 3 p. m.

IMPORTANCE OF DIFFERENCES

From the above we see that the use of different times for the termination of the "day" may considerably affect the record of minimum temperature, especially by producing numerous, and at times large, variations in the minima recorded for the same dates. Data for stations that use different time limits for the day are, therefore, not comparable. For instance: If minimum temperature data for Harlingen be obtained by using the late afternoon-ending day, those for Mission by use of the 7- or 8-a. m.-ending day, and those for Brownsville by using the midnight-to-midnight day, wide differences in the records are necessarily introduced, which may accentuate or cancel any real differences that exist among these stations, all of which are located in the lower Rio Grande Valley. While frequencies and amounts of differences would doubtless be different in other sections of the country, variations of similar nature may be expected there. It is true, of course, that daily positive and negative departures tend to cancel each other in resultant monthly sums and averages; but the daily values and frequencies are the more important biologically, for the mean temperature is not actually experienced.[3]

It is, therefore, very desirable that an at least approximately uniform time be adopted for the termination of the periods to be used in finding daily minimum (as well as maximum) temperatures at all stations. It remains to be seen which time is most desirable. If we examine a series of thermograms for any section of the United States we see that (excepting such unusual cases as those already referred to in connection with cold-waves, cases when daily amplitude of temperature is negligible, etc.) the curves showing the march of temperature are irregular periodic wavy lines, in general form similar to a sinusoid curve but having varying amplitudes and extremes of ordinates; maxima and minima each occurring at approximately 24-hour intervals. Each hollow of low temperature, represented by its minimum, is of course separated by crests of higher temperature from adjacent hollows; and, similarly, each daily crest of high temperature is separated from adjacent crests by hollows of low temperature. The effects of each crest and hollow of the daily march of temperature upon the daily periodic activities of vegetable and animal life, as well as upon human comfort and activities, are consequently separated from the effects of adjoining crests and hollows, respectively, by effects of intervening periods of temperature of the opposite sense. Therefore, from a biological standpoint, each daily recorded maximum temperature should be the highest between immediately preceding and following minima; and each daily minimum should be the lowest between the immediately preceding and following maxima.

If all stations had thermographs, such desired data could readily be obtained; but the majority of stations are not so equipped, temperature data being generally obtained from maximum and minimum thermometers only. If we read and set the maximum thermometer at about the usual time of the early morning minimum, say, at 7 or 8 a. m., local time, we obtain the maximum of the preceding 24 hours' wave crest and we set the thermometer at a proper time to obtain the maximum of the next succeeding crest. Similarly, if we read and set the minimum thermometer at about the usual time of the daily maximum temperature, say at about 3 p. m., we obtain the minimum of the preceding hollow of low temperature and we set our minimum thermometer at a proper time to obtain the minimum of the next succeeding hollow. It would have been better, therefore, if we had taken 3 p. m. instead of 6 p. m. as our standard time in our study of minimum temperature data, above. However, we have found differences between the 3 and the 6 p. m. data at Rio Grande Valley stations to be relatively infrequent and of no great importance. Under ordinary conditions some latitude exists in choosing a time that is fairly suitable; and it is for this reason that we can select

[3] "A Classification of Weather Types", by E. S. Nichols, MONTHLY WEATHER REVIEW, October 1925, 431–434. Also "Das Klima als Wettergesammtheit", translated and summarized by E. S. Nichols, MONTHLY WEATHER REVIEW, September 1927, 55, 401–403.

a time that is fairly satisfactory for reading and setting both thermometers.

The ideal situation can almost be obtained with little difficulty at special stations with paid observers who take and transmit temperature observations daily in the early morning, if we adopt the following arrangements, which have heretofore been made in the lower Rio Grande Valley Frost Service and, it is understood, to some extent elsewhere: Both thermometers are to be read and set at the early-morning observation; in addition the minimum thermometer, only, is to be read and set in the late afternoon or early evening (say, at about sunset). The morning readings (maximum during the preceding 24 hours, minimum during the night just ended) are telegraphed or otherwise transmitted; while the maximum then read is entered under the current date on the monthly-report form, but is set back to the preceding date (on which it almost always occurs) in published reports. The minimum to be recorded for any date is the lower of the two minima read on that date, this being the lowest temperature of the 24 hours ending at the sunset observation. The additional late-afternoon reading and setting of the minimum thermometer can doubtless be required of paid special observers generally; while in cases where compensation allowed for observers' services is insufficient, the great improvement in minimum-temperature records that would result (as compared with once-daily early-morning observations) appears to warrant a small additional allowance for services. It seems, also, that as many as practicable of the other non-thermograph stations should make temperature observations and records according to the same system, which may be looked on as a goal to be reached if practicable.

ONCE DAILY OBSERVATIONS

At a majority of stations, however, it appears that for the present for practical reasons both thermometers must be read and set at the same time, since most observers are cooperative and unpaid. Our study of data herewith has shown that the early morning is a very unsuitable time for a single daily observation, because of effects on the minimum-temperature record. Neither can 3 p.m. nor other time near that of the daily maximum be chosen, because maxima thus obtained would often be too high as compared with the true maximum from minimum to minimum. An intermediate time must be selected, which should be, if consistent with reasonable accuracy, convenient for the cooperative observers generally. Although late forenoon would produce fairly accurate results, such time would be generally inconvenient. Any generally convenient and accurate time must be later than the ususal time of the daily maximum.

If we consider midnight: An examination of the Harlingen thermograph traces for the 12 months used in our minimum-temperature study shows that true maxima are obtained in all but 5 or 6 percent of all dates; in most of the exceptional cases temperature had not, by midnight, fallen as low as the maxima of the immediately following day, while in some other cases no true maximum crest appears on the thermograms. Thus, very satisfactory maximum data would be obtained by midnight observations. However, we have found that in the data we have studied the midnight-to-midnight minima differ in about one-fourth of all cases from the standard. This is not satisfactory. Also, midnight is an impossible time for making cooperative-station observations; so also is, in general, any time much later than about sunset or 6 p. m.

By 6 p. m. (in data studied) temperature had usually fallen lower than the maximum of the next-following day; but a further examination of the Harlingen thermograms previously used shows that in about 12 percent of the cases the maximum for the 6 p. m.-ending day was too high. These differences are to be regretted; but we have found that 6 p. m. gives very satisfactory minimum temperatures; and it is also usually convenient, and is, on the whole, the most satisfactory.

CONCLUSION

We may, therefore, conclude:

(1) That at thermograph stations and at other stations where twice-daily observations can be taken, daily maximum temperatures should be obtained for the 24 hours ending at about the usual time of the early morning minima while daily minima should be taken for 24-hour periods ending in the afternoon, say, about sunset or 6 p. m.

(2) That at nonthermograph stations at which twice-daily observations cannot be taken, the once-daily observations should be taken in the late afternoon or early evening, say, at about sunset or 6 p. m., as now at most cooperative stations.

(3) That once-daily early morning observations produce minimum-temperature records so misleading that such observations should be discontinued as far as practicable.

In this manner minimum temperatures would be obtained for the same periods at all stations, and would thus be truly comparable (as well as correct), while the daily maxima obtained usually would be comparable.

The effects of variations in time of observations upon daily and monthly mean temperatures is not considered herein. This matter has been previously investigated.[2]

[2] See footnote 2 on p. 338.

TABLE 1.—*Effects of variations in the period taken as the day upon the record of minimum temperature at Harlingen, Tex. (during 12 selected months)*

Periods	Departures from 6 p. m. to 6 p. m. minimum temperatures, numbers of differing cases and amounts of differences																														Number of days with minimum temperatures of—											
	7 a. m. to 7 a. m. minima										8 a. m. to 8 a. m. minima										Midnight to midnight minima										40° or below (days ending)				32° or below (days ending)				25° or below (days ending)			
	Positive departures			Negative departures			Total differences		Resultant		Positive departures			Negative departures			Total differences		Resultant		Positive departures			Negative departures			Total differences		Resultant													
	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily average	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily average	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily average	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.
December 1931	+10	2	+5	−59	12	−18	69	4.9	−49	−1.6	+11	2	+6	−45	11	−16	56	4.3	−34	−1.1	+11	5	+5	−38	6	−12	49	4.5	−27	−0.9	1	1	1	1	0	0	0	0	0	0	0	0
1932	+18	3	+10	−62	13	−13	80	5.0	−44	−1.4	+20	3	+11	−44	8	−11	64	5.8	−24	−0.8	+12	4	+4	−29	7	−7	41	3.7	−17	−0.5	7	7	7	7	2	2	1	1	0	0	0	0
1933	+11	1	+11	−64	17	−9	75	4.2	−53	−1.7	+9	1	+9	−19	7	−6	28	3.5	−10	−0.3	+1	1	+1	−21	6	−7	22	3.1	−20	−0.6	2	1	1	1	0	0	0	0	0	0	0	0
3 Decembers	+39	6	+11	−185	42	−18	224	4.7	−146	−1.6	+40	6	+11	−148	26	−16	−148	4.6	−68	−0.7	+24	10	+5	−88	19	−12	112	3.9	−64	−0.7	10	9	9	9	2	2	1	1	0	0	0	0
January 1932	+30	6	+11	−103	11	−24	133	7.8	−73	−2.4	+30	5	+12	−79	10	−21	109	7.3	−49	−1.6	+8	4	+3	−35	8	−8	43	3.6	−27	−0.9	4	3	4	3	0	0	0	0	0	0	0	0
1933	+8	2	+4	−91	13	−15	99	6.6	−83	−2.7	+5	2	+3	−57	11	−13	62	4.8	−52	−1.7	0	0	0	−20	7	−6	20	2.9	−20	−0.6	2	2	1	1	0	0	0	0	0	0	0	0
1934	+18	5	+7	−56	11	−12	74	4.6	−38	−1.2	+14	3	+7	−44	10	−10	58	4.5	−30	−1.0	+4	2	+3	−24	9	−10	28	2.5	−20	−0.6	0	0	0	0	0	0	0	0	0	0	0	0
3 Januarys	+56	13	+11	−250	35	−24	306	6.4	−194	−2.1	+49	10	+12	−180	31	−21	229	5.6	−131	−1.4	+12	6	+3	−79	24	−10	91	3.0	−67	−0.7	6	5	5	4	0	0	0	0	0	0	0	0
February 1932	+4	1	+4	−55	14	−13	59	3.9	−51	−1.7	+4	1	+4	−39	9	−10	43	4.3	−35	−1.2	0	0	0	−13	5	−6	13	2.6	−13	−0.4	0	0	0	0	0	0	0	0	0	0	0	0
1933	+22	6	+6	−63	9	−20	85	5.7	−41	−1.5	+17	5	+6	−44	9	−15	61	4.4	−27	−1.0	+1	1	+1	−34	6	−20	35	5.0	−33	−1.2	5	5	4	3	3	2	2	2	0	0	0	0
1934	+12	1	+12	−50	14	−7	62	4.1	−38	−1.4	+13	2	+12	−11	5	−4	24	3.4	+2	+0.1	+1	1	+1	−25	2	−13	26	8.7	−24	−0.8	0	0	0	0	0	0	0	0	0	0	0	0
3 Februarys	+38	8	+12	−168	37	−20	206	4.6	−130	−1.5	+34	8	+12	−94	23	−15	128	4.1	−60	−0.7	+2	2	+1	−72	13	−20	74	4.9	−70	−0.8	5	5	4	3	3	2	2	2	0	0	0	0
March 1932	+13	2	+11	−93	13	−18	106	7.1	−80	−2.6	+9	2	+8	−49	8	−13	58	5.8	−40	−1.3	+2	1	+2	−36	9	−7	38	3.8	−34	−1.1	9	8	8	7	4	3	3	2	0	0	0	0
1933	+4	2	+3	−70	10	−16	74	6.2	−66	−2.1	+4	1	+4	−44	8	−18	48	5.3	−40	−1.3	+2	1	+2	−30	6	−10	32	4.6	−28	−0.9	0	0	0	0	0	0	0	0	0	0	0	0
1934	+22	2	+19	−52	14	−10	74	4.6	−30	−1.0	+20	2	+19	−12	5	−5	32	4.6	+8	+0.3	+1	1	+1	−15	2	−11	16	5.3	−14	−0.5	2	2	2	2	0	0	0	0	0	0	0	0
3 Marches	+39	6	+19	−215	37	−18	254	5.9	−176	−1.9	+33	5	+19	−105	21	−18	138	5.3	−72	−0.8	+5	3	+2	−81	17	−11	86	4.3	−76	−0.8	11	10	10	9	4	3	3	2	0	0	0	0
Frequencies of differing cases:																																										
Total numbers		33			151				184			29			101				130			21			73				94		7	4	3	..	4	2	1	..	0	0	0	0
Percentages									51										36										26		28	16	12	..	80	40	20	..	0	0	0	0

TABLE 2.—*Effects of variations in the period taken as the day upon the record of minimum temperature at Mission, Tex. (during 12 selected months)*

Periods	Departures from 6 p. m. to 6 p. m. minimum temperatures, numbers of differing cases and amounts of differences																														Number of days with minimum temperatures of—											
	7 a. m. to 7 a. m. minima										8 a. m. to 8 a. m. minima										Midnight to midnight minima										40° or below (days ending)				32° or below (days ending)				25° or below (days ending)			
	Positive departures			Negative departures			Total differences		Resultant		Positive departures			Negative departures			Total differences		Resultant		Positive departures			Negative departures			Total differences		Resultant													
	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.
December 1931	+9	2	+5	−68	8	−19	77	7.7	−59	−1.9	+9	2	+5	−47	6	−16	56	7.0	−38	−1.2	0	0	0	−44	9	−16	44	4.9	−44	−1.4	2	2	1	1	0	0	0	0	0	0	0	0
1932	+14	2	+8	−75	13	−17	89	5.9	−61	−2.0	+13	2	+7	−57	10	−14	70	5.8	−44	−1.4	+1	1	+1	−34	8	−7	35	3.9	−33	−1.1	8	8	8	8	2	2	3	2	0	0	0	0
1933	0	0	0	−81	18	−10	81	4.5	−81	−2.6	0	0	0	−44	12	−9	44	3.7	−44	−1.4	+1	1	+1	−20	5	−9	21	4.2	−19	−0.6	4	2	2	2	0	0	0	0	0	0	0	0
3 Decembers	+23	4	+8	−224	39	−19	247	5.7	−201	−2.2	+22	4	+7	−148	28	−16	170	5.3	−126	−1.4	+2	2	+1	−98	22	−16	100	4.2	−96	−1.0	14	12	11	11	2	2	3	2	0	0	0	0
January 1932	+21	5	+9	−91	12	−23	112	6.6	−70	−2.3	+21	4	+9	−69	10	−18	90	6.4	−48	−1.5	+5	2	+3	−66	9	−18	71	6.5	−61	−2.0	5	3	3	3	0	0	0	0	..	..	..	..
1933	0	0	0	−96	12	−16	96	8.0	−96	−3.1	0	0	0	−61	11	−13	61	5.5	−61	−2.0	0	0	0	−16	4	−9	16	4.0	−16	−0.5	3	3	2	2	2	1	1	1	..	..	..	..
1934	+8	2	+4	−45	8	−14	53	5.3	−37	−1.2	+9	3	+4	−35	8	−10	44	4.0	−26	−0.8	+2	1	+2	−27	8	−14	29	3.2	−25	−0.8	0	0	0	0	0	0	0	0	..	..	..	..
3 Januarys	+29	7	+9	−232	32	−23	261	6.7	−203	−2.2	+30	7	+9	−165	29	−18	195	5.4	−135	−1.5	+7	3	+3	−109	21	−18	116	4.8	−102	−1.1	8	6	5	5	2	1	1	1	0	0	0	0
February 1932	0	0	0	−61	14	−14	61	4.4	−61	−2.1	0	0	0	−33	7	−12	33	4.7	−33	−1.1	0	0	0	−8	3	−5	8	2.7	−8	−0.3	0	0	0	0	0	0	0	0	..	..	..	..
1933	+10	5	+4	−63	8	−23	73	5.6	−53	−1.9	+9	5	+3	−53	8	−21	62	4.8	−44	−1.6	+3	2	+2	−26	4	−18	29	4.8	−23	−0.8	6	5	6	5	3	3	2	2	..	..	..	..
1934	+11	1	+11	−54	13	−10	65	4.6	−43	−1.5	+11	1	+11	−44	15	−8	55	3.4	−33	−1.2	0	0	0	−27	3	−13	27	9.0	−27	−1.0	2	1	1	1	0	0	0	0	..	..	..	..
3 Februarys	+21	6	+11	−178	35	−23	199	4.9	−157	−1.8	+20	6	+11	−130	30	−21	150	4.2	−110	−1.3	+3	2	+2	−61	10	−18	64	5.3	−58	−0.7	8	6	7	6	3	3	2	2	0	0	0	0
March 1932	+8	1	+8	−100	13	−17	108	7.7	−92	−3.0	0	0	0	−29	7	−8	29	4.1	−29	−0.9	0	0	0	−24	6	−9	24	4.0	−24	−0.8	9	7	7	7	3	2	2	2	..	..	..	..
1933	0	0	0	−72	11	−15	72	6.5	−72	−2.3	0	0	0	−30	7	−10	30	4.3	−30	−1.0	0	0	0	−20	6	−6	20	3.3	−20	−0.6	0	0	0	0	0	0	0	0	..	..	..	..
1934	+20	1	+20	−67	17	−10	87	4.8	−47	−1.5	+20	1	+20	−16	5	−5	36	6.0	+4	+0.1	+1	1	+1	−17	2	−13	17	6.0	−16	−0.5	5	4	4	4	0	0	0	0	..	..	..	..
3 Marches	+28	2	+20	−239	41	−17	267	6.2	−211	−2.3	+20	1	+20	−75	19	−10	95	4.8	−55	−0.6	+1	1	+1	−61	14	−13	61	4.1	−60	−0.6	14	11	11	11	3	2	2	2	0	0	0	0
Differing cases:																																										
Total numbers					166												124										75				11	2	1	..	3	1	1	..	0	0	0	0
Percentage frequencies					46												34										21				33	6	3	..	43	14	14	..	0	0	0	0

TABLE 3.—*Effects of variations in the period taken as the day upon the record of minimum temperature at Dilley, Tex. (during 12 selected months)*

Periods	Departures from 6 p. m. to 6 p. m. minimum temperatures, numbers of differing cases and amounts of differences																														Number of days with minimum temperature of—											
	7 a. m. to 7 a. m. minima										8 a. m. to 8 a. m. minima										Midnight to midnight minima										40° or below (days ending)				32° or below (days ending)				25° or below (days ending)			
	Positive departures			Negative departures			Total differences		Resultant departure		Positive departures			Negative departures			Total differences		Resultant departure		Positive departures			Negative departures			Total differences		Resultant departure													
	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	Sums	Numbers	Greatest	Sums	Numbers	Greatest	Sums	Averages	Sums	Daily averages	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.	7 a. m.	8 a. m.	Midnight	6 p. m.
December 1931	+7	1	+7	−60	11	−14	67	5.6	−53	−1.7	+9	1	+9	−28	6	−8	37	5.3	−19	−0.6	0	0	0	−32	7	−12	32	4.6	−32	−1.0	13	11	12	10	1	1	1	1	0	0	0	0
1932	+3	2	+2	−63	10	−11	66	5.5	−60	−1.9	+5	2	+3	−45	10	−15	50	4.2	−40	−1.3	+3	1	+3	−24	5	−8	27	4.5	−21	−0.7	17	15	12	12	4	4	4	3	2	1	1	1
1933	+3	1	+3	−69	14	−10	72	4.8	−66	−2.1	+4	1	+4	−44	11	−10	48	4.0	−40	−1.3	+2	1	+2	−39	5	−13	41	6.8	−37	−1.2	8	7	7	6	0	0	0	0	0	0	0	0
3 Decembers	+13	4	+7	−192	35	−14	205	5.3	−179	−1.9	+18	4	+9	−117	27	−15	135	4.4	−99	−1.1	+5	2	+3	−95	17	−13	100	5.3	−90	−1.0	38	33	31	28	5	5	5	4	2	1	1	1
January 1932	+2	1	+2	−77	9	−20	79	7.9	−75	−2.4	+2	1	+1	−65	9	−18	67	6.7	−63	−2.0	+9	2	+5	−43	7	−12	52	5.8	−34	−1.1	15	15	14	13	2	1	1	1	0	0	0	0
1933	+7	2	+4	−99	12	−12	106	7.6	−92	−3.0	+5	2	+3	−84	10	−14	89	7.4	−79	−2.5	+6	2	+5	−12	4	−6	18	3.0	−6	−0.2	7	6	5	5	3	2	2	2	2	1	1	1
1934	+12	6	+3	−84	12	−16	96	5.3	−72	−2.3	+5	2	+3	−74	12	−14	79	5.6	−69	−2.2	0	0	0	−24	6	−12	24	4.0	−24	−0.8	12	12	10	10	4	3	3	3	0	0	0	0
3 Januarys	+21	9	+4	−260	33	−20	281	6.7	−239	−2.6	+12	5	+3	−223	31	−18	235	6.5	−211	−2.3	+15	4	+5	−79	17	−12	94	4.5	−64	−0.7	34	33	29	28	9	6	6	6	2	1	1	1
February 1932	+10	1	+10	−62	14	−12	72	4.7	−52	−1.8	+11	1	+11	−35	8	−11	46	5.1	−24	−0.8	+7	1	+7	−20	4	−8	27	5.4	−13	−0.4	2	2	1	1	0	0	0	0	0	0	0	0
1933	+9	4	+5	−79	11	−25	88	5.9	−70	−2.5	+9	3	+5	−68	11	−22	77	5.5	−59	−2.1	0	0	0	−25	6	−17	25	4.2	−25	−0.9	8	7	7	6	6	5	6	4	3	3	2	2
1934	0	0	0	−68	14	−17	68	4.9	−68	−2.4	0	0	0	−61	12	−16	61	5.1	−61	−2.2	+2	1	+2	−24	2	−13	26	8.7	−22	−0.8	9	9	7	7	2	2	1	1	0	0	0	0
3 Februarys	+19	5	+10	−209	39	−25	228	5.2	−190	−2.2	+20	4	+11	−164	31	−22	184	5.3	−144	−1.7	+9	2	+7	−69	12	−17	78	5.6	−60	−0.7	19	18	15	14	8	7	7	5	3	3	2	2
March 1932	+6	1	+6	−87	10	−18	93	8.5	−81	−2.6	+6	1	+6	−41	9	−14	47	4.7	−35	−1.1	0	0	0	−32	6	−9	32	5.3	−32	−1.0	11	10	10	10	7	6	6	6	0	0	0	0
1933	+4	1	+4	−77	16	−10	81	4.8	−73	−2.4	+5	1	+5	−52	11	−8	57	4.8	−47	−1.5	0	0	0	−9	3	−4	9	3.0	−9	−0.3	2	1	1	1	0	0	0	0	0	0	0	0
1934	+17	2	+16	−82	15	−12	99	5.8	−65	−2.1	+19	2	+18	−23	8	−8	42	4.2	−4	−0.1	+2	1	+2	−4	1	−4	6	3.0	−2	−0.1	11	8	7	7	2	1	1	1	0	0	0	0
3 Marches	+27	4	+16	−246	41	−18	273	6.1	−219	−2.4	+30	4	+18	−116	28	−14	146	4.6	−86	−0.9	+2	1	+2	−45	10	−9	47	4.3	−43	−0.5	24	19	18	18	9	7	7	7	0	0	0	0
Differing cases:																																										
Total number					170										134									65							27	15	5		9	3	3		3	1	0	
Percentage frequency					47										37									18							31	17	6		41	14	14		75	25	0	

TABLE 4.—*Effects of variations in the period taken as the day upon the record of minimum temperature at Harlingen, Tex. (during 12 selected months)*

Periods	9 a. m. to 9 a. m. minima: Positive departures: Sums	Numbers	Greatest	Negative departures: Sums	Numbers	Greatest	Total differences: Sums	Averages	Resultant departures: Sums	Daily averages
December 1931	+12	2	+7	−16	3	−10	28	5.6	−4	−0.1
1932	+21	4	+8	−17	4	−7	38	5.4	+4	+0.1
1933	+7	1	+7	−6	1	−6	13	6.5	+1	0
3 Decembers	+40	7	+8	−39	8	−10	79	5.3	+1	0
January 1932	+29	4	+13	−45	7	−14	74	6.7	−16	−0.5
1933	+3	1	+3	−19	3	−8	22	5.5	−16	−0.5
1934	+16	4	+7	−15	3	−6	31	4.4	+1	0
3 Januarys	+48	9	+13	−79	13	−14	127	5.8	−31	−0.3
February 1932	+1	1	+1	−15	5	−7	16	2.7	−14	−0.5
1933	+11	4	+5	−22	5	−10	33	3.7	−11	−0.4
1934	+15	2	+14	−2	1	−2	17	5.7	+13	+0.5
3 Februarys	+27	7	+14	−39	11	−10	66	3.7	−12	−0.2
March 1932	+8	1	+8	−15	4	−6	23	4.6	−7	−0.2
1933	+2	1	+2	−2	1	−2	4	2.0	0	0
1934	+19	1	+19	−6	2	−4	25	8.3	+13	+0.4
3 Marches	+29	3	+19	−23	7	−6	52	5.2	+6	+0.1
Differing cases: Total numbers	---	26	---	---	39	---	---	---	65	
Percentage frequencies	---	---	---	---	---	---	---	---	18	

Periods	10 a. m. to 10 a. m. minima: Positive departures: Sums	Numbers	Greatest	Negative departures: Sums	Numbers	Greatest	Total differences: Sums	Averages	Resultant departures: Sums	Daily averages
December 1931	+12	2	+7	0	0	0	12	6.0	+12	+0.4
1932	+23	4	+8	−9	3	−4	32	4.6	+14	+0.5
1933	+6	1	+6	−5	1	−5	11	5.5	+1	0
3 Decembers	+41	7	+8	−14	4	−5	55	5.0	+27	+0.3
January 1932	+28	3	+13	−7	3	−5	35	5.8	+21	+0.7
1933	+3	1	+3	−3	1	−3	6	3.0	0	0
1934	+18	4	+7	0	0	0	18	4.5	+18	+0.6
3 Januarys	+49	8	+13	−10	4	−5	59	4.9	+39	+0.4
February 1932	0	0	0	−3	1	−3	3	3.0	−3	−0.1
1933	+9	3	+4	−6	1	−6	15	3.8	+3	+0.1
1934	+15	2	+14	0	0	0	15	7.5	+15	+0.5
3 Februarys	+24	5	+14	−9	2	−6	33	4.7	+15	+0.2
March 1932	+8	1	+8	−2	1	−2	10	5.0	+6	+0.2
1933	+2	1	+2	0	0	0	2	2.0	+2	+0.1
1934	+8	1	+8	−3	1	−3	11	5.5	+5	+0.2
3 Marches	+18	3	+8	−5	2	−3	23	4.6	+13	+0.1
Differing cases: Total numbers	---	23	---	---	12	---	---	---	35	
Percentage frequencies	---	---	---	---	---	---	---	---	10	

Periods	Noon to noon minima: Positive differences: Sums	Numbers	Greatest	Negative departures: Sums	Numbers	Greatest	Total differences: Sums	Averages	Resultant departures: Sums	Daily averages
December 1931	+12	2	+7	0	0	0	12	6.0	+12	+0.4
1932	+18	3	+7	−2	1	−2	20	5.0	+16	+0.5
1933	+2	1	+2	−1	1	−1	3	1.5	+1	0
3 Decembers	+32	6	+7	−3	2	−2	35	4.4	+29	+0.3
January 1932	+7	2	+4	−1	1	−1	8	2.7	+6	+0.2
1933	+3	1	+3	0	0	0	3	3.0	+3	+0.1
1934	+18	4	+7	0	0	0	18	4.5	+18	+0.6
3 Januarys	+28	7	+7	−1	1	−1	29	3.6	+27	+0.3
February 1932	0	0	0	−1	1	−1	1	1.0	−1	0
1933	+7	2	+4	0	0	0	7	3.5	+7	+0.2
1934	+13	2	+12	0	0	0	13	6.5	+13	+0.5
3 Februarys	+20	4	+12	−1	1	−1	21	4.0	+19	+0.2
March 1932	+8	1	+8	0	0	0	8	8.0	+8	+0.3
1933	+2	1	+2	0	0	0	2	2.0	+2	+0.1
1934	+2	1	+2	−2	1	−2	4	2.0	0	0
3 Marches	+12	3	+8	−2	1	−2	14	3.5	+10	+0.1
Differing cases: Total numbers	---	20	---	---	5	---	---	---	25	
Percentage frequencies	---	---	---	---	---	---	---	---	7	

Periods	3 p. m. to 3 p. m. minima: Positive departures: Sums	Numbers	Greatest	Negtive departures: Sums	Numbers	Greatest	Total differences: Sums	Averages	Resultant departures: Sums	Daily averages
December 1931	+9	2	+7	0	0	0	9	4.5	+9	+0.3
1932	+13	3	+7	−1	1	−1	14	3.5	+12	+0.4
1933	+1	1	+1	0	0	0	1	1.0	+1	0
3 Decembers	+23	6	+7	−1	1	−1	24	3.4	+22	+0.2
January 1932	+5	2	+3	0	0	0	5	2.5	+5	+0.2
1933	+4	1	4	0	0	0	4	4.0	+4	+0.1
1934	+12	4	+5	0	0	0	12	3.0	+12	+0.4
3 Januarys	+21	7	+5	0	0	0	21	3.0	+21	+0.2
February 1932	0	0	0	0	0	0	0	0	0	0
1933	+5	2	+4	0	0	0	5	2.5	+5	+0.2
1934	+1	1	+1	0	0	0	1	1.0	+1	0
3 Februarys	+6	3	+4	0	0	0	6	2.0	+6	+0.1
March 1932	+4	1	+4	0	0	0	4	4.0	+4	+0.1
1933	+2	1	+2	0	0	0	2	2.0	+2	+0.1
1934	0	0	0	0	0	0	0	0	0	0
3 Marches	+6	2	+4	0	0	0	6	3.0	+6	+0.1
Differing cases: Total numbers	---	18	---	---	1	---	---	---	---	19
Percentage frequencies	---	---	---	---	---	---	---	---	---	5

Periods	Number of days with minima of—: 40° or below (days ending): 9 a. m.	10 a. m.	Noon	3 p. m.	32° or below (days ending): 9 a. m.	10 a. m.	Noon	3 p. m.
December 1931	1	1	1	1	0	0	0	0
1932	7	7	7	7	2	1	1	1
1933	1	1	1	1	0	0	0	0
3 Decembers	9	9	9	9	2	1	1	1
January 1932	3	3	3	3	0	0	0	0
1933	1	1	1	1	0	0	0	0
1934	0	0	0	0	0	0	0	0
3 Januarys	4	4	4	4	0	0	0	0
February 1932	0	0	0	0	0	0	0	0
1933	4	4	3	3	2	2	2	2
1934	0	0	0	0	0	0	0	0
3 Februarys	4	4	3	3	2	2	2	2
March 1932	7	7	7	7	2	2	2	2
1933	0	0	0	0	0	0	0	0
1934	2	2	2	2	0	0	0	0
3 Marches	9	9	9	9	2	2	2	2
Differing cases: Total numbers	1	1	0	0	1	0	0	0
Percentage frequencies	4	4	0	0	20	0	0	0

THE TROPICAL DISTURBANCE OF AUGUST 26-31, 1934

By W. R. STEVENS

[Weather Bureau, Washington, October 1934]

Disturbed conditions were first observed in connection with this storm on the morning of August 26, when two vessels in the north-central Gulf of Mexico reported squalls, and the wind velocity at Port Eads, La., was 28 m. p. h. from the east. During the night of August 25, 5.50 inches of rain fell at Port Eads. By the night of the 26th there had been an increase in wind velocity and a decrease in pressure, with a movement of the disturbed condition toward the west-northwest. However, no definite center had developed at this time; but storm warnings were issued for the Texas coast between Port Arthur and Port O'Connor. By the morning of the 27th a definite center had developed and was located about 50 miles east of Galveston, the lowest reported pressure being 29.46 inches, and the highest wind velocity 70 m. p. h. (estimated). A maximum wind velocity of 30 m. p. h. from the east-northeast was recorded at Port Arthur during the night of August 26. Storm warnings were changed to hurricane warnings from Port Arthur to Galveston at 8:30 a. m. E. S. T. on August 27, and hurricane warnings were issued west of Galveston to Freeport at 2:45 p. m. Caution was also advised against possibility of dangerous gales west of Freeport to Matagorda. It was apparent at this time that the disturbance was turning more to the west or west-southwest. After the 27th, the storm moved south-southwestward, and crossed the Mexican coast a short distance north of Tampico during the night of August 31. Such a course of a tropical disturbance along the Texas coast is unprecedented.

The lowest pressure reported at any coastal station was 29.62 inches at Galveston on the 27th. Approximately the same pressure was recorded by independent observers at Freeport during the early morning of the 28th.

The highest wind velocities recorded at coastal stations during the storm were as follows: Port Arthur, 34 m. p. h.; Galveston, 42 m. p. h.; and Freeport, 50-60 m. p. h. (estimated).

The lowest pressure and highest wind velocity were reported by the steamship *Simon von Utrecht* on the afternoon of August 28, when the vessel was about 75 miles south-southwest of Galveston: Pressure, 29.34 inches; wind velocity, 80 m. p. h. (estimated).

There was no serious damage along the Texas coast. After receipt of the storm warnings on August 26, beaches and low sections were evacuated, and precautions taken against property damage in the danger zone indicated in the warnings. No loss of life was reported on the coast or at sea.

BIBLIOGRAPHY

C. FITZHUGH TALMAN, in Charge of Library

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Commonwealth solar observatory

Memoir. Canberra. 1934. no. 3. Measurements of atmospheric ozone made at the Commonwealth solar observatory, Mount Stromlo, Canberra, during the years 1929 to 1932, by A. J. Higgs, B. Sc. Canberra. March 1934. 29 p. figs., plates. 31 cm.

Leighly, John Barger

Marquesan meteorology. Notes on the meteorologic observations made in the Marquesas islands by the Pacific entomological survey during the years 1929-1932, by John B. Leighly, Berkeley, California, University of California press, 1933. p. 147-172 incl. illus. (map), tables, diagrs. 26 cm. (University of California publications in geography. v. 6, no. 4.)

United States. Coast & geodetic survey

Alaska magnetic tables and magnetic charts for 1930, by Daniel L. Hazard, chief magnetician, Division of terrestrial magnetism and seismology. Washington, U. S. Govt. printing office, 1934. 35 p. incl. tables. 4 fold. charts. 23 cm. (Serial no. 570.) At head of title: U. S. Department of commerce. Daniel C. Roper, secretary. Coast and geodetic survey. R. S. Patton, director . . . Lithographed.

SOLAR OBSERVATIONS

SOLAR RADIATION MEASUREMENTS DURING SEPTEMBER 1934

By IRVING F. HAND, Assistant in Solar Radiation Investigations

For a description of instruments employed and their exposures, the reader is referred to the January 1932 REVIEW, page 26.

Table 1 shows that solar radiation intensities averaged above normal for September at all three Weather Bureau stations.

Table 2, on the other hand, shows a deficiency in the amount of total solar and sky radiation received on a horizontal surface at all stations except Fairbanks, Alaska.

Table 3 shows lower turbidity values and less water content of the atmosphere than were recorded during the summer months.

Polarization measurements obtained on 6 days at Washington give a mean of 54 percent, with a maximum of 60 percent on the 17th. At Madison measurements made on 7 days give a mean of 57 percent with a maximum of 63 percent on the 17th. The values at Washington are close to the September normals, while those at Madison are somewhat below normal.

TABLE 1.—*Solar radiation intensities during September 1934*

[Gram-calories per minute per square centimeter of normal surface]

WASHINGTON, D. C.

Date	8 a. m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
	mm	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm
Sept. 1	8.81				1.12	1.25					9.14
Sept. 4	15.65					1.45	1.14				15.65
Sept. 17	9.83	0.76	0.84	0.97	1.17	1.42					10.97
Sept. 18	9.14	.76	.87	.99							8.81
Sept. 19	9.14					1.21					9.83
Sept. 20	11.38			.60	.82						11.81
Sept. 28	8.18			.95	1.11						8.81
Means		(.76)	(.86)	.88	1.06	1.33	(1.14)				
Departures		+.07	+.11	+.01	+.02	+.02	+.08				

MADISON, WIS.

Date	e	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	e
Sept. 5	9.83		0.82	0.97	1.14						9.14
Sept. 7	8.18		1.05	1.17	1.30	1.49					8.48
Sept. 8	8.48		.95	1.10	1.24						7.29
Sept. 17	6.50		.92	1.08	1.30	1.49	1.24				7.04
Sept. 25	15.11		.79	.95	1.16						15.65
Sept. 27	4.57	0.94	1.00	1.07	1.32	1.59	1.25				4.95
Means		(.94)	.89	1.06	1.24	1.49	(1.24)				
Departures		+.08	−.01	+.04	+.08	+.09	+.07				

* Extrapolated.

TABLE 1.—*Solar radiation intensities during September 1934*—Con.

LINCOLN, NEBR.

Date	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A.M.					Air mass P.M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	*1.9	2.0	3.0	4.0	5.0	e.
	mm	cal	cal	cal	cal	cal	cal	cal	cal	cal	mm
Sept. 4	7.87	0.86	0.98	1.12	1.27	1.46					8.18
Sept. 6	7.29				1.31	1.51	1.29	1.06	0.99	0.86	6.02
Sept. 7	6.50	.82	.96	1.02	1.31	1.51	1.31	1.17	1.03	.93	6.02
Sept. 8	7.29	.86	.98	1.12	1.29	1.52					6.76
Sept. 11	10.97	.85	.93	1.05	1.20	1.43	1.17	.96	.77	.62	16.79
Sept. 12	18.59				1.13	1.30	1.10	.95	.82	.70	17.96
Sept. 15	5.79	.99	1.09	1.24	1.39	1.55					4.95
Sept. 17	7.29	.65	.75	.93							11.38
Sept. 18	7.57	.84	.96	1.08	1.26	1.43	1.19	1.02	.86	.76	7.87
Sept. 19	7.87	.67	.80	.93	1.13	1.32					11.38
Sept. 21	5.16			.97	1.23	1.47	1.29	1.10	.92	.78	4.95
Sept. 22	7.04	.70	.84	.97	1.16	1.34					7.32
Sept. 27	5.79	.84	.98	1.13	1.36	1.56	1.28	1.08	.90		6.27
Sept. 28	8.18						1.11	1.00	.84	.76	12.24
Means		.81	.93	1.05	1.25	1.45	1.22	1.04	.89	.77	
Departures		+.09	+.11	+.10	+.13	+.04	+.07	+.06	+.05	+.04	

BLUE HILL, MASS.

Date	e.	5.0	4.0	3.0	2.0	*1.9	2.0	3.0	4.0	5.0	e.
Sept. 1	9.6				1.07	1.27	1.05				7.4
Sept. 11	11.1				1.09	1.38	1.15	0.94			11.1
Sept. 13	10.7						1.21	.98			7.6
Sept. 20	12.8		1.14	1.21	1.31	1.42					12.3
Sept. 25	13.2				1.23	1.43	1.12	.90			13.7
Sept. 26	14.3			1.05	1.19	1.31	1.15	.90			16.1
Sept. 28	7.9		1.05	1.19	1.33	1.41	1.18	.97	0.84		7.9
Means			(1.10)	1.15	1.20	1.37	1.14	.94	(.84)		

TABLE 2.—*Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface*

Week beginning—	Washington	Madison	Lincoln	Chicago	New York	Fresno	Pittsburgh	Fairbanks	Twin Falls	La Jolla	Miami	New Orleans	Riverside	Blue Hill	Mount Washington	Friday Harbor
	Gram-calories per square centimeter															
1934	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Sept. 3	314	317	488		255	601	406	203	523	478	461	437	492	312	356	
Sept. 10	228	278	443		229	580	265	331	525	463	286	237	440	284	376	331
Sept. 17	392	278	374	311	258	451	280	243	396	463	331	367	364	191	300	
Sept. 24	315	288	304	290	251	544	201	193	396	517	418	276	480	282	283	
	Departures from weekly normals															
Sept. 3	−69	−59	+26		−58	+50	+48	−64	−3		+11	+53				
Sept. 10	−34	−61	+2		−76	+53	−67	+48	+19		−160	−119				
Sept. 17	+33	−63	−39	−4	−41	−39	−35	+90	−82		−119	+23				
Sept. 24	−35	−3	−71	+31	−25	+84	−89	+73	−58		−26	−73				
	Accumulated departures on Sept. 30															
	+1,694	−3,465	+5,803		+12,791	+8,981	−2,499	+133	+4823		−7,084	+7,035				

TABLE 2-a.—*Late reports from Mount Washington. Lightning and wind have destroyed 2 pyrheliometers this year*

[Average daily totals of solar radiation (direct+diffuse) received on a horizontal surface at Mount Washington, N. H.]

Week beginning—		Week beginning—		Week beginning—	
1934	cal.	1934	cal.	1934	Cal.
Apr. 30	515	May 28	679	June 25	452
May 7	512	June 4	645	Aug. 20	527
May 14	641	June 11	359	Aug. 27	407
May 21	478	June 18	485		

TABLE 3.—*Total, I_m, and screened, I_y, I_r, solar radiation intensity measurements, obtained during September 1934, and determinations of the atmospheric turbidity factor, β, and water-vapor content, w=depth in millimeters, if precipitated*

AMERICAN UNIVERSITY, WASHINGTON, D. C.

Date and hour angle	Solar altitude		Air mass	I_m	I_y	I_r	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$\frac{I_{w=0}}{1.94}$	$\frac{I_{w=0}-I_m}{1.94}$	w	Air-mass type
										Percentage of solar constant			
Sept. 17, 1934	°	'	m	gr. cal.	gr. cal.	gr. cal.						mm	
4:43 a.	16	26	3.51	0.897	0.725	0.586	0.075	0.055	0.065	57.5	46.4	7	P_c
4:39 a.	17	54	3.23	.923	.726	.587	.073	.067	.070	58.4	47.6	7	
4:31 a.	18	40	3.10	.953	.728	.589	.068	.070	.069	60.8	49.1	11	
4:28 a.	19	14	3.00	.971	.725	.590	.057	.065	.061	63.3	50.1	12	
4:17 a.	21	20	2.74	1.037	.764	.615	.052	.068	.060	65.0	53.5	11	
4:13 a.	22	05	2.64	1.029	.765	.616	.064	.071	.068	64.8	53.0	12	
4:09 a.	22	50	2.57	1.066	.777	.633	.067	.079	.072	64.8	55.6	4	
4:06 a.	23	20	2.52	1.065	.778	.634	.059	.079	.069	65.8	55.5	5	
3:23 a.	31	10	1.93	1.192	.885	.702	.068	.056	.062	72.8	61.4	13	
3:20 a.	31	40	1.90	1.204	.886	.704	.069	.059	.064	72.8	62.1	9	
2:37 a.	38	54	1.59	1.274	.914	.729	.063	.059	.061	72.4	65.7	3	
2:32 a.	39	42	1.56	1.283	.914	.730	.067	.059	.063	72.6	66.1	2	
1:37 a.	47	14	1.36	1.323	.948	.749	.068	.048	.058	75.0	68.2	3	
1:33 a.	47	42	1.34	1.326	.948	.749	.068	.048	.058	75.6	68.9	4	
Sept. 18, 1934													
4:46 a.	15	36	3.68	.928	.721	.591	.058	.062	.062	57.0	48.4	3	P_c
4:41 a.	16	32	3.49	.938	.721	.592	.059	.069	.064	58.7	48.7	5	
4:33 a.	18	01	3.21	.993	.745	.596	.045	.055	.050	63.5	51.7	10	
4:28 a.	19	57	2.92	1.000	.745	.596	.052	.060	.056	64.0	51.2	17	
4:13 a.	21	50	2.66	1.032	.786	.637	.073	.073	.073	63.2	51.5	14	
4:08 a.	22	45	2.58	1.056	.787	.638	.066	.074	.070	64.8	54.9	7	
Sept. 20, 1934													
3:08 a.	32	54	1.84	.845	.662	.548	.200	.096	.148	59.2	44.0	50	N_{pc}
3:03 a.	33	44	1.80	.846	.662	.548	.200	.100	.150	59.0	44.1	48	
Sept. 28, 1934													
4:29 a.	16	15	3.55	.880	.717	.578	.079	.055	.067	60.1	45.5	28	P_c
4:25 a.	17	10	3.36	.903	.718	.581	.076	.058	.067	59.5	46.5	18	
4:02 a.	21	12	2.75	1.020	.781	.620	.068	.054	.061	65.0	52.6	16	
3:57 a.	22	05	2.64	1.032	.783	.621	.065	.058	.062	65.8	53.2	12	
3:14 a.	29	36	2.02	1.107	.842	.669	.088	.062	.075	68.6	57.7	10	
3:09 a.	30	27	1.97	1.096	.842	.669	.099	.065	.082	68.0	56.5	15	
2:28 a.	36	52	1.67	1.158	.837	.669	.088	.100	.092	69.3	59.7	7	
2:22 a.	37	47	1.63	1.140	.837	.669	.106	.102	.104	68.3	58.8	8	
0:26 a.	48	43	1.32	1.138	.822	.646	.124	.110	.117	71.7	58.6	34	
0:22 a.	48	52	1.32	1.138	.822	.646	.124	.110	.117	71.7	58.7	33	

Atmospheric conditions during turbidity measurements

Sept. 17: Temperature, 15° C.; wind, NW. 15; visibility, 30 miles; polarization, 60 percent; blueness of sky, 6.
Sept. 18: Temperature, 14° C.; wind, NW. 13; visibility, 20 miles; polarization, 50 percent; blueness of sky, 5.
Sept. 20: Temperature, 14° C.; wind, SE. 10; visibility, 20 miles; polarization, 54 percent; blueness of sky, 5.
Sept. 28: Temperature, 15° C.; wind, E. 12; visibility, 30 miles; polarization, 54 percent; blueness of sky, 5.

TABLE 3.—*Total, I_m, and screened, I_y, I_r, solar radiation intensity measurements, obtained during September 1934, and determinations of the atmospheric turbidity factor β and water-vapor content, w=depth in millimeters, if precipitated*

BLUE HILL OBSERVATORY OF HARVARD UNIVERSITY

Date and hour angle	Solar altitude		Air mass	I_m	I_y	I_r	$\beta_{I_{m-r}}$	$\beta_{I_{y-r}}$	β_{mean}	$\frac{I_{w=0}}{1.94}$	$\frac{I_{w=0}-I_m}{1.94}$	w	Air-mass type
										Percentage of solar constant			
Sept. 1, 1934	°	'	m	gr. cal.	gr. cal.	gr. cal.						mm	
3:49 a. m.	29	10	2.04	1.065	0.796	0.645	0.116	0.086	0.101	63.8	7.9	3.0	P_c
2:55 a. m.	38	50	1.59	1.158	.835	.663	.091	.077	.084	72.3	14.1	43.0	
4:04 p. m.	26	56	2.26	.999	.754	.614	.098	.090	.094	62.8	10.4	7.9	N_{pc} T_m aloft.
Sept. 11, 1934													
1:52 a. m.	44	56	1.41	1.351	.938	.750	.049	.062	.056	78.0	7.4	3.1	N_{pc}
0:55 a. m.	50	31	1.29	1.279	.888	.703	.074	.081	.078	77.0	11.0	17.8	
3:00 p. m.	35	13	1.73	1.263	.883	.690	.037	.028	.032	80.5	14.5	56.0	P_A, T_m aloft.
Sept. 13, 1934													
3:00 p. m.	34	34	1.76	1.295	.885	.690	.021	.033	.027	80.0	12.6	25.0	P_A
4:14 p. m.	21	21	2.74	.983	.743	.592	.060	.055	.058	63.5	14.0	27.1	T_m aloft.
Sept. 25, 1934													
1:42 a. m.	40	46	1.53	1.328	.876	.679	.022	.042	.032	82.0	13.2	35.0	T_m
1:17 p. m.	43	39	1.45	1.278	.874	.662	.033	.017	.025	84.0	18.3	60.+	Thin N_{pc}
4:18 p. m.	17	39	3.28	.889	.666	.536	.060	.074	.067	59.5	13.4	17.4	T_m aloft.
Sept. 26, 1934													
3:58 a. m.	21	14	2.75	1.074	.756	.603	.033	.047	.040	71.1	15.7	51.0	N_{pc}
0:12 a. m.	46	33	1.38	1.351	.907	.706	.027	.026	.026	84.9	14.9	86.0	T_m aloft.
2:34 p. m.	34	08	1.78	1.229	.832	.649	.033	.051	.042	77.8	14.1	44.6	
2:50 p. m.	32	05	1.88	1.176	.799	.639	.042	.041	.042	77.1	16.2	60.+	N_{pc}
3:49 p. m.	22	48	2.57	.964	.723	.603	.096	.103	.100	58.5	8.6	3.2	T_m aloft.
Sept. 28, 1934													
3:51 a. m.	21	52	2.66	1.220	.852	.716	.030	------	.030	73.6	10.5	6.9	N_{pc}
1:51 a. m.	39	14	1.58	1.399	.972	.719	.032	.047	.040	80.0	7.7	3.6	
2:19 p. m.	35	53	1.70	1.245	.878	.713	.066	.090	.078	71.9	7.5	2.9	N_{pc}
4:20 p. m.	13	20	4.28	.905	.709	.590	.055	.050	.052	57.4	10.6	4.5	

Atmospheric conditions during solar radiation measurements, Blue Hill Observatory of Harvard University

Date and time from apparent noon	Air temperature	Wind (Beaufort scale)	Visibility; scale, 0–10	Sky blueness	Cloudiness and remarks
September 1934	°C.				
1; 2:54 a. m.	17.8	SE 3	9, se, 5 sw	4	Few Cu, 1 Ci.
1; 3:40 p. m.	17.7	ESE 4	8–9	6	4 Ci.
11; 1:57 a. m.	19.4	WNW 2		4	4 Acu, 1 Cu.
11; 1:58 a. m.	20.6	NW 3	8	5	Few Acu, 6 Cu.
13; 3:01 p. m.	15.4	NE 4		8	5 Ci, few Acu, few Stcu.
13; 4:19 p. m.	14.9	ENE 3			5 Ci, 3 Cu, few Stcu.
25; 1:56 a. m.	19.3	NE 3		7	Few Ci, few Stcu, 1 Cu.
25; 0:56 p. m.	21.0	NNE 1		6	Few Ci, few Cu. (Cl'ds interrupted radiation meas'ts.)
25; 4:00 p. m.	19.8	NE 1	8+	7	Few Ci, few Cu.
26; 4:04 a. m.	18.3	S 2	7	8	Clear, with fog on horizon.
26; 2:37 p. m.	26.1	S 2	8	6	Few Cu.
26; 4:14 p. m.	25.0	SxW 3		6	Few Ci, few Cu.
26; 0:22 a. m.	23.9	S 2		6	Few Cu.
28; 4:00 a. m.	12.2	WNW 2	4, n, 6, w	6	Few Cist, lt. hz, Smk over Boston.
28; 2:00 a. m.	13.9	WNW 2	8 sw, 7 e	6–7	Smk to 5° over Boston.
28; 2:09 p. m.	18.3	WSW 2	7	6	Few Acu, sse horizon.
28; 4:12 p. m.	19.4	WSW 2		5	1 Acu & Cu, west horizon.

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. J. F. Hellweg, U. S. Navy, Superintendent U. S. Naval Observatory. Data furnished by the U. S. Naval Observatory in cooperation with Harvard and Mount Wilson Observatories. The difference in longitude is measured from the central meridian, positive west. The north latitude is positive. Areas are corrected for foreshortening and are expressed in millionths of the sun's visible hemisphere. The total area for each day includes spots and groups]

Date	Eastern standard time		Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day	Observatory
1934	h	m	°	°	°				
Sept. 1	11	22		No spots					U. S. Naval.
Sept. 2	10	34		No spots					Do.
Sept. 3	11	0		No spots					Mount Wilson.
Sept. 4	13	18		No spots					U. S. Naval.
Sept. 5	13	29		No spots					Do.
Sept. 6				No spots					Harvard.
Sept. 7	9	0		No spots					Mount Wilson.
Sept. 8	9	30		No spots					Do.
Sept. 9				No spots					Harvard.
Sept. 10	13	8		No spots					U. S. Naval.
Sept. 11	13	11		No spots					Do.
Sept. 12	11	40	−1.0	173.8	−30.0		9	9	Mount Wilson.
Sept. 13				No spots					Harvard
Sept. 14	11	45	+25.0	173.4	−30.0		27		Mount Wilson.
			+50.0	198.4	+7.0		8	35	
Sept. 15	12	18	+62.0	196.9	+7.0	46		46	U. S. Naval.
Sept. 16	12	25	+77.0	198.6	+7.0		115	115	Mount Wilson.
Sept. 17	11	14		No spots					U. S. Naval.

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standatd time		Heliographic: Diff. in longitude	Heliographic: Longitude	Heliographic: Latitude	Area: Spot	Area: Group	Total area for each day	Observatory
1934	h	m	°	°	°				
Sept. 18	11	26		No spots					U. S. Naval.
Sept. 19	11	30		No spots					Do.
Sept. 20	11	16		No spots					Do.
Sept. 21	9	15		No spots					Mount Wilson.
Sept. 22	11	48		No spots					U. S. Naval.
Sept. 23	12	37		No spots					Do.
Sept. 24	12	41		No spots					Do.
Sept. 25	14	29		No spots					Do.
Sept. 26	11	8		No spots					Do.
Sept. 27	11	49		No spots					Do.
Sept. 28	11	39	+7.0	330.7	+23.0	31		31	Do.
Sept. 29	13	0	−66.0	243.8	−12.0		6		Mount Wilson.
			+7.0	316.8	−2.5		4		
			+21.0	330.8	+22.0		8		
			+50.0	359.8	−29.0		6	24	
Sept. 30	11	30	+34.0	331.4	+23.0		62	62	U. S. Naval.
Mean daily area for 30 days								11	

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR SEPTEMBER 1934

(Dependent alone on observations at Zurich and its station at Arosa)

[Data furnished through the courtesy of Prof. W. Brunner, Eidgen. Sternwarte, Zurich, Switzerland]

September 1934	Relative numbers	September 1934	Relative numbers	September 1934	Relative numbers
1	0	11	0	21	0
2	0	12	7	22	0
3	7	13	7	23	7
4	0	14	8	24	0
5	0	15	*Wc*16	25	0
6	0	16	9	26	0
7	0	17	8	27	0
8	0	18	0	28	9
9	0	19	0	29	14
10		20	0	30	21

Mean: 29 days = 3.9.

c = New formation of a center of activity: *E*, on the eastern part of the sun's disk; *W*, on the western part; *M*, in the central circle zone.

AEROLOGICAL OBSERVATIONS

[Aerological Division, D. M. Little, in charge]

By L. T. SAMUELS

Free-air temperatures during September averaged lowest over the northwestern section of the country and highest over southern California. (See table 1.) Departures from normal, at those stations with sufficiently long records, were small, and were negative at the lower levels and positive at the upper levels.

Free-air relative humidities averaged lowest over the middle and southern Pacific coast and highest over the middle Atlantic coast, the difference being about 30 percent.

Resultant free-air wind directions over the eastern part of the country contained a greater southerly component than normal. (See table 2.) In most cases the resultant velocities were below normal in this region. Elsewhere resultant directions were close to normal, and velocities generally above normal.

TABLE 1.—*Free-air temperatures and relative humidities obtained by airplanes during September 1934*

TEMPERATURE (° C.)

Station	Surface		500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
Altitude (meters) m. s. l.	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Billings, Mont.[1] (1,090 m.)	9.4						11.1		9.2		6.8		3.3		−3.5		−9.5	
Cheyenne, Wyo.[1] (1,873 m.)	6.2								8.1		9.8		7.1		0.3		−6.9	
Fargo, N. Dak.[1] (274 m.)	8.1		10.6		10.5		8.4		6.9		5.1		2.4		−2.7		−8.4	
Fort Crockett (Galveston), Tex.[2] [3] (3 m.)	25.2		23.8		21.0		18.5		16.5		14.2		11.4		5.1		−0.4	
Kelly Field (San Antonio), Tex.[2] (211 m.)	21.9		22.5		21.3		19.1		16.8		14.5		11.9		5.5		−1.2	
Maxwell Field (Montgomery), Ala.[2] (52 m.)	19.2		22.4		19.5		17.0		14.8		12.1		9.4		3.2		−2.9	
Mitchel Field (Hempstead, L. I.), N. Y.[2] (39 m.)	16.8		17.6		15.8		14.5		12.6		10.4		7.5		1.8		−4.0	
Murfreesboro, Tenn.[1] (174 m.)	17.1		19.4		18.0		15.3		12.9		10.1		7.6		2.0		−4.0	
Norfolk, Va.[4] (3 m.)	21.2	−1.3	20.6	−0.6	18.4	−0.5	15.9	−0.2	13.4	0.0	10.8	+0.1	8.5	+0.4	3.0	+0.4	−2.6	+0.4
Oklahoma City, Okla.[1] (391 m.)	16.5		17.1		18.1		17.0		14.6		11.4		8.4		1.5		−4.7	
Omaha, Nebr.[1] (300 m.)	11.9	(6)	13.6	(6)	15.3	−1.0	13.5	−0.6	11.5	+0.1	9.0	+0.7	6.2	+1.0	−0.4	+0.2	−7.1	−1.1
Pearl Harbor, Territory of Hawaii[4] (5 m.)	23.7	−3.6	22.3	−0.5	18.8	+0.1	15.6	−0.1	13.1	+0.3	11.2	+0.1	9.2	0.0	3.5	0.0	−2.3	0.0
Philadelphia, Pa.[4] (3 m.)	19.1		18.1		16.0		13.9		12.1		9.3		6.9		1.1		−5.3	
San Diego, Calif.[4] (10 m.)	18.3	−1.1	19.5	+2.3	20.5	+1.4	20.1	+1.6	17.7	+0.2	15.4	+0.5	12.9	+0.8	7.0	+1.1	0.6	+1.1
Scott Field (Belleville), Ill.[3] (135 m.)	14.8		17.2		15.8		14.2		11.3		8.2		5.2		−0.9		−7.4	
Selfridge Field (Mount Clemens), Mich.[2] (177 m.)	15.7		17.7		15.7		13.1		10.6		8.2		5.6		0.3		−4.9	
Spokane, Wash.[5] (596 m.)	9.1				12.9		10.5		7.2		4.0		1.0		−4.8		−11.0	
Sunnyvale, Calif.[4] (6 m.)	15.3		14.2		18.1		17.7		14.8		11.2		7.6		−0.5			
Washington, D. C.[4] (2 m.)	19.4	−1.0	18.7	−0.5	16.9	−0.6	15.2	−0.1	13.3	+0.3	11.1	+0.4	8.5	+0.3	3.2	+0.6	−3.2	+0.4
Wright Field (Dayton), Ohio[2] (244 m.)	14.8		16.3		16.3		13.7		11.1		8.3		5.7		−0.3		−6.1	

RELATIVE HUMIDITY (PERCENT)

Station	Surface		500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
Altitude (meters) m. s. l.	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Billings, Mont.[1] (1,090 m)	66						57		55		52		54		60		51	
Cheyenne, Wyo.[1] (1,873 m)	67								62		49		47		46		47	
Fargo, N. Dak.[1] (274 m)	83		73		67		62		57		53		52		43		44	
Fort Crockett (Galveston), Tex.[2] [3] (3 m)	84		80		72		65		58		54		54		53		47	
Kelly Field (San Antonio), Tex.[2] (211 m)	93		89		80		74		67		59		53		45		43	
Maxwell Field (Montgomery), Ala.[2] (52 m)	94		64		66		60		49		45		42		46		39	
Mitchel Field (Hempstead, L. I.), N. Y.[2] (39 m)	93		80		75		66		61		56		57		52		48	
Murfreesboro, Tenn.[1] (174 m)	90		74		72		71		66		62		57		49		41	
Norfolk, Va.[4] (3 m)	87	+9	81	+11	81	+14	79	+14	75	+12	71	+12	64	+10	57	+10	53	+10
Oklahoma City, Okla.[1] (391 m)	85		79		63		56		53		53		50		47		40	
Omaha, Nebr.[1] (300 m)	87	(6)	77	(6)	63	+4	59	+3	54	0	47	−8	45	−9	45	−6	42	−7
Pearl Harbor, Territory of Hawaii[4] (5 m)	85	+17	80	+6	83	+4	80	+5	71	+2	53	−1	42	+1	34	+1	33	+1
Philadelphia, Pa.[4] (3 m)	86		79		78		65		61		60		54		48		39	
San Diego, Calif.[4] (10 m)	83	+7	70	−9	55	−2	42	−2	39	+7	35	+6	34	+7	33	+8	31	+8
Scott Field (Belleville), Ill.[3] (135 m)	92		70		67		55		50		52		47		45		38	
Selfridge Field (Mount Clemens), Mich.[2] (177 m)	90		71		68		66		62		58		55		49		43	
Spokane, Wash. [5](596 m)	68				48		47		50		55		55		48		45	
Sunnyvale, Calif.[4] (6 m)	75		74		47		36		33		30		27		25			
Washington, D. C.[4] (2 m)	81	+5	75	+6	75	+10	66	+3	58	−3	53	−5	51	−3	46	−4	31	−4
Wright Field (Dayton), Ohio[2] (244 m)	92		79		67		66		59		53		49		46		38	

[1] Weather Bureau.
[2] Army.
[3] June to November, inclusive, only.
[4] Navy.
[5] National Guard.
[6] Surface and 500-meter level departures omitted because of difference in time of day between airplane observations and those of kites upon which the normals are based.

Observations taken about 5 a. m., 75th meridian time, except along the Pacific coast and Hawaii where they are taken about 5 a. m., local standard time.

LATE REPORTS FOR AUGUST, 1934

TEMPERATURE (°C.)

Station	Altitude (meters) m. s. l.																	
	Surface		500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Philadelphia, Pa.[1] (3 m)	20.3		19.6		17.4		14.6		10.8		8.1		5.8		0.2		−6.1	
Washington, D. C.[1] (2 m)	18.5	−4.2	18.9	−2.6	17.5	−2.0	15.4	−1.3	12.9	−0.9	10.5	−0.5	8.1	−0.1	2.8	+0.1	−3.8	0.0

RELATIVE HUMIDITY (PERCENT)

Station	Surface		500		1,000		1,500		2,000		2,500		3,000		4,000		5,000	
Philadelphia, Pa.[1] (3 m)	82		73		66		65		67		60		55		41		35	
Washington, D. C.[1] (2 m)	85	+9	74	+5	73	+8	74	+8	72	+5	66	+3	57	−2	48	−6	47	−5

[1] Navy.

TABLE 2.—*Free-air resultant winds (meters per second) based on pilot-balloon observations made near 7 a. m. (E. S. T.) during September 1934*

[Wind from N=360°, E=90°, etc.]

Altitude (m) m. s. l.	Albuquerque, N. Mex. (1,554 m)		Atlanta, Ga. (309 m)		Bismarck, N. Dak. (518 m)		Brownsville, Tex. (7 m)		Burlington, Vt. (132 m)		Cheyenne, Wyo. (1,873 m)		Chicago, Ill. (192 m)		Cleveland, Ohio (245 m)		Dallas, Tex. (154 m)		Havre, Mont. (762 m)		Jacksonville, Fla. (14 m)		Key West, Fla. (11 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	39	1.2	350	0.6	345	0.9	100	1.2	170	3.0	279	3.0	227	1.2	180	2.4	155	1.9	276	1.1	316	1.3	90	1.9
500			3	0.3			143	7.1	190	7.3			238	5.2	222	5.6	192	6.1			45	0.6	102	4.3
1,000			248	1.9	264	3.5	160	7.4	222	5.5			243	5.7	249	5.7	203	6.3	272	2.6	79	1.0	107	4.2
1,500			235	2.5	277	4.1	161	6.5	239	5.2			248	7.2	243	6.4	214	3.7	292	6.1	66	0.5	113	3.1
2,000	229	0.3	242	2.7	286	4.4	160	5.3	250	4.8	277	4.6	256	7.4	237	6.9	249	2.7	292	7.4	84	0.7	128	2.6
2,500	272	3.6	242	3.7	287	6.1	150	4.6	237	5.6	291	6.7	253	7.3	238	7.2	285	3.0	284	7.8	122	0.3	122	2.5
3,000	271	6.3	245	3.9	284	9.0	138	3.8	238	5.3	292	8.4	248	7.6	239	7.0	325	3.5	288	10.1	198	0.8	137	1.4
4,000	273	6.2	244	4.2	296	11.6	126	2.4	225	5.9	293	10.4			245	8.6	312	2.4	288	12.6	222	1.2	54	0.7
5,000	269	6.6	240	3.2			102	0.9			293	9.0			252	9.8	284	4.6			241	2.7		

Altitude (m) m. s. l.	Los Angeles, Calif. (217 m)		Medford, Oreg. (410 m)		Memphis, Tenn. (83 m)		New Orleans, La. (19 m)		Oakland, Calif. (8 m)		Oklahoma City, Okla. (402 m)		Omaha, Nebr. (306 m)		Phoenix, Ariz. (338 m)		Salt Lake City, Utah (1,294 m)		Sault Ste. Marie, Mich. (198 m)		Seattle, Wash. (14 m)		Washington, D. C. (10 m)	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	348	0.4	186	0.4	188	0.7	97	2.0	260	0.5	140	1.0	142	0.7	89	1.6	147	2.7	24	0.2	123	1.1	320	0.9
500	0	0	298	0.6	216	6.4	142	4.0	246	1.8	169	4.5	205	2.4	182	0.6			171	2.3	178	0.1	344	2.3
1,000	360	0.2	308	1.2	229	7.0	155	4.7	344	2.8	211	9.1	246	4.5	270	2.4			229	4.7	10	1.4	314	4.2
1,500	7	0.7	22	0.4	231	6.5	170	3.3	3	2.0	227	8.0	256	5.5	267	2.8	154	2.7	231	3.9	340	2.3	260	4.8
2,000	249	0.7	7	0.8	243	5.0	161	2.4	343	2.3	243	6.9	279	5.4	236	2.8	230	1.4	244	6.5	338	2.6	277	5.8
2,500	211	1.7	276	2.2	237	4.0	174	1.8	191	0.2	248	5.3	291	7.4	220	3.5	272	2.6	252	8.8	329	4.5	263	6.7
3,000	210	2.5	266	4.4	229	4.3	117	0.7	148	1.6	291	5.6	306	7.3	218	4.3	284	4.5	257	7.2	307	4.9	251	8.3
4,000	187	3.4	281	5.9			325	2.6			330	5.8	293	5.8	235	6.1	291	8.9	249	3.6	343	6.6		
5,000	214	3.3	282	6.3											252	8.4	290	11.7						

RIVERS AND FLOODS

By RICHMOND T. ZOCH

[River and Flood Division, Montrose W. Hayes, in charge]

The table shows the places at which flood stages were reached during September. The overflows in the Roanoke, Wisconsin, Bourbeuse, Meramec, and Purgatoire Rivers caused slight damage; elsewhere no damage resulted.

In addition to the above floods, heavy rains near Hartford, Conn., caused the small streams to overflow, and there was considerable damage. High water broke a dam on Middle Creek in Snyder County, Pa. The entire damage for this Middle Creek flood was estimated at slightly less than $70,000.

Table of flood stages during September 1934

[All dates are in September]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC SLOPE DRAINAGE	*Feet*			*Feet*	
Schuylkill: Reading, Pa	10	30	30	10.5	30
James: Columbia, Va	18	17	17	19.8	17
Roanoke:					
Weldon, N. C	31	9	10	36.9	9
		18	20	34.7	19
Williamston, N. C	10	13	27	11.0	23, 24
Tar: Greenville, N. C	12	20	22	12.8	21
Neuse:					
Neuse, N. C	13	17	20	15.4	19
Smithfield, N. C	12	18	21	13.5	20
Cape Fear: Elizabethtown, N. C	20	18	19	22.3	19
Santee: Rimini, S. C	12	1	2	13.9	2
		19	21	13.3	19
		27	27	12.2	27

Table of flood stages during September 1934—Continued

River and station	Flood stage	Above flood stages—dates		Drest	
		From—	To—	Stage	Date
MISSISSIPPI SYSTEM					
Upper Mississippi Basin	*Feet*			*Feet*	
Wisconsin: Knowlton, Wis	12	27	27	12.0	27
Bourbeuse: Union, Mo	12	15	17	14.1	16
Meramec:					
Pacific, Mo	11	15	18	17.8	17
Valley Park, Mo	14	16	19	18.0	18
Arkansas Basin					
Purgatoire: Higbee, Colo	4	15	15	11.0	15
North Canadian:					
Canton, Okla	5	10	10	5.5	10
Yukon, Okla	7	2	2	7.7	2
		10	11	7.6	10
Arkansas: Fort Lyon, Colo	6	15	15	9.4	15

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

[The Marine Division, W. F. McDonald, in charge]

NORTH ATLANTIC OCEAN

By H. C. HUNTER

Atmospheric pressure.—The pressure averaged moderately higher than normal over most of the southeastern and northwestern parts of the North Atlantic; but considerably lower than normal in the northeastern, where Reykjavik, Iceland, was 0.22 inch below normal. Otherwise the departures of average pressure were very small.

Over the ocean no pressure reading was noted higher than that of 30.51 inches on the German liner *Bremen*, about noon of the 14th, in latitude 44° N., longitude 43° W. The lowest pressure, 28.15 inches, was encountered by the Swedish motorship *Blankaholm*, at 11 p. m., the 27th, in 57° N., 23° W.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure (sea level) at selected stations for the North Atlantic Ocean and its shores, September 1934*

Stations	Average pressure	Departure	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.68	----------	30.00	6, 16	29.37	24, 26
Reykjavik, Iceland	29.50	−0.22	30.15	5	28.87	26
Lerwick, Shetland Islands	29.76	−.08	30.33	13	29.37	24
Valencia, Ireland	29.81	−.18	30.32	12	29.45	3
Lisbon, Portugal	30.13	+.11	30.48	1	29.97	6
Madeira	30.11	+.09	30.44	20	30.01	8
Horta, Azores	30.15	−.02	30.40	1	29.92	5, 27
Belle Isle, Newfoundland	30.06	+.16	30.46	22	29.48	28
Halifax, Nova Scotia	30.20	+.15	30.54	1	29.74	19
Nantucket	30.11	+.03	30.49	1	29.69	18
Hatteras	30.04	−.02	30.26	1	29.26	8
Bermuda	30.12	+.04	30.28	9	30.04	12, 13, 17, 18
Turks Island	29.98	.00	30.04	9, 10, 23	29.92	12, 13
Key West	29.96	+.02	30.12	23	29.84	7
New Orleans	30.01	+.03	30.19	1	29.84	15

NOTE.—All data based on a. m. observations only, with departures compiled from best available normals related to time of observation, except Hatteras, Key West, Nantucket, and New Orleans, which are 24-hour corrected means.

Cyclones and gales.—During the first 10 days, storm activity affected two widely separated parts of the North Atlantic Ocean. One of these was situated between the thirtieth meridian and the Irish, English, and French coasts; the other between the American coast south of New England and the sixty-fifth meridian. On the 2d, reports of fresh to strong gales came from waters within about 500 miles southwest of Ireland, while on the same day a Low of moderate energy was approaching the Carolinas from the southeast, to move inland and northward on the following day. After a brief interval without gales, a tropical cyclone appeared near the Bahamas, and on the 6th a whole gale (force 10) was encountered by the American steamship *Syros*, then about 100 miles northeast of Great Abaco Island. The next day a like force was noted by the American steamship *West Texas*, when approximately 170 miles south of Cape Hatteras (chart VIII).

Early on the 8th the center of this storm passed very close to Hatteras and thereafter continued to move northward and slightly eastward. The task of rescue from the burning American liner *Morro Castle*, off the New Jersey coast, was hampered by the strong winds connected with this storm; but fortunately it was practically completed before the greatest force occurred, the Sandy Hook station showing its highest velocity, 65 miles, between 8 and 9 p. m. of the 8th.

Two vessels near the coast between Cape Hatteras and Cape May encountered winds of force 12 on the 8th, in each case from a southwesterly point. The American steamer *Solana* met the greatest force about 7 a. m., near latitude 36° N., and the Dutch steamer *Amor* about 3 p. m., near 38°. Late on the 8th the storm center moved inland over southern New England and lost strength rapidly.

About this time several vessels encountered gales along the eastern portion of the steamship lanes to northern Europe; the greatest force there at this time was 10 (whole gale), met by the Dutch liner *Statendam* during the afternoon of the 9th, about 51° N., 26° W.

During the remainder of the month no storm worth mention affected the waters near the Atlantic and Gulf coasts of the United States; and the whole North Atlantic during the period from the 14th to 22d, inclusive, was almost free from gales, except that a small-area storm of marked strength (force 11) but with no particularly low barometric reading, was met about 2 p. m., on the 18th, between Bermuda and Fayal, by the American steamship *Yaka*. No report other than that from the *Yaka* has been received relating to this storm.

The final week of September included a moderate number of storm reports, nearly all these gales being met

between the forty-third and sixtieth parallels and the twentieth and fortieth meridians. The British tanker *Lustrous* noted force 12 late on the 25th, when at about 45° N., 23° W. Two other vessels noted force 10 about that time, in positions considerably northwestward from the *Lustrous*. Chart IX shows the situation on the morning of the 26th.

Tropical storms.—Mention has been made of the tropical storm which was near the Bahama Islands on the 6th. This was apparently of minor importance till it had moved north of the Tropic of Cancer. Also the less important storm in about the same region a few days earlier has been mentioned; but this probably did not even start south of the Tropic. About the middle of the month a depression was noted to be moving northwestward, passing close to the Virgin Islands, but it seems never to have reached marked strength, and by the 21st, between the Bahamas and Bermuda, it ceased to be identifiable. One radio report indicated force 9 on the 17th, in connection with this storm, but no mail report of more than force 7 has come to hand. Other than these, North Atlantic waters south of latitude 30° seem to have had no storm of any consequence during September.

Fog.—While there seems to have been comparatively little fog in the steamship lanes east of the thirty-fifth meridian, reports indicate that over and near the Grand Banks there was generally a little more fog than is usual during September. The 5° square, 45° to 50° N., 45° to 50° W., took the lead in this area, having fog on 10 days; it was especially prevalent during the third week. Near the American coast several squares had considerably more than normal occurrence of fog, the square 40° to 45° N., 65° to 70° W., reporting 16 days.

WATERSPOUT OVER CHESAPEAKE BAY, SEPTEMBER 12, 1934

[Abstract of a report by John J. Murphy, in charge of Weather Bureau Office, Norfolk, Va.]

Between 10:06 and 10:21 a. m. September 12, 1934, a fully developed waterspout was observed over Lynnhaven Roads, in extreme lower Chesapeake Bay, about a mile off shore, and 10 to 12 miles east-northeast of Norfolk. It formed beneath a heavy cumulo-nimbus cloud out of which rain was falling, traveled at a rate of about 10 m. p. h. in a westerly or northwesterly direction, and rotated counterclockwise.

The spout was located at some distance in front of the rain sheet which accompanied the thundercloud. Formation of the spout was not observed, but its disappearance began with a break at a point in midair, between cloud and water surface. By a fortunate coincidence, Lt. Critchfield Adair, United States Navy, was aloft in an airplane near the scene, and he flew to and circled the formation to make careful observations. He is quoted in the Norfolk Virginian-Pilot of September 13, as follows:

"The spout's top ended in the clouds, 1,000 feet above the water. Dark and funnel-shaped, it appeared to me to be based in a white ball of spray 125 feet in diameter. A little higher it narrowed abruptly to about 30 feet and spread out to about 100 feet in diameter at the top."

Lieutenant Adair is also reported to have observed that the moving spout left a sharp and well-defined wake on the surface of the bay. Observers on shore described the sea surface as greatly agitated at the base of the spout, with spray carried to an estimated height of 50 feet.—*W. F. McD.*

OCEAN GALES AND STORMS, SEPTEMBER 1934

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Black Gull, Am. S. S.	Antwerp	New York	50 24 N.	23 40 W.	Sept. 2	4a, 2	Sept. 2	29.08	WSW	W, 9	W	W, 9	WSW-W.
Pastores, Am. S. S.	Port-au-Prince.	do	31 18 N.	74 24 W.	Sept. 1	4a, 2	do	29.77	N	NE, 9	NE	NE, 9	
Nubian, Br. S. S.	Antwerp	do	49 57 N.	15 00 W.	Sept. 2	4p, 2	do	29.37	WSW	W, 8	W	W, 8	WSW-W.
Silvercedar, Br. M. S.	Nassau, Bahamas.	London	[1] 48 16 N.	21 54 W.	Sept. 1	8p, 2	Sept. 3	29.56	SW	W, 8	W	W, 9	Steady.
Amor, Du. S. S.	Maracaibo	New York	32 44 N.	76 20 W.	do	9p, 2	Sept. 1	29.73	NNW	NW, 6	NNE	NNE, 9	NNW-NW-SW.
Washington, Am. S. S.	New York	Cobh	50 40 N.	18 00 W.	Sept. 2	Noon, 3.	Sept. 2	29.58	NW	W, 7	NW	NW, 8	None.
Marguerite Finaly, Fr. M. S.	Havre	Cartagena	46 00 N.	12 30 W.	Sept. 5	2a, 6	Sept. 6	29.58	SE	SSE, 9	SW	SE, 10	SE-SSE-SW.
Syros, Am. S. S.	Antwerp	Tampico	26 52 N.	75 19 W.	do	6p, 6	do	29.71	SE	SE, 8	SE	SE, 10	None.
Java Arrow, Am. S. S.	New York	Texas City	29 10 N.	78 00 W.	Sept. 7	6a, 7	Sept. 7	29.53	ENE	E, 5	NE	ENE, 9	E-N.
Orizaba, Am. S. S.	do	Habana	29 36 N.	77 24 W.	do	11a, 7	do	28.92	E	W, 7	W	E, 9	E-W.
West Texas, Am. S. S.	Philadelphia	Houston	32 30 N.	76 20 W.	do	9p, 7	Sept. 8	29.16	E	E, 3	S	SE, 10	E-SE-S.
Sapinero, Am. S. S.	Houston	Lisbon	33 51 N.	75 52 W.	do	2a, 8	do	29.43	ENE	Calm	W	E, 9	SE-N-NW.
Solana, Am. S. S.	Fall River	Houston	36 10 N.	74 33 W.	Sept. 8	6a, 8	do	29.17	SE	SW, 12	WSW	WSW, 12.	ESE-SW-WSW.
Amor, Du. S. S.	New York	Curacao	[1] 37 50 N.	73 00 W.	do	3p, 8	do		SE	SSW, 10	SW	SW, 12	S-SW.
Vacuum, Am. S. S.	do	Beaumont	39 40 N.	73 30 W.	do	6p, 8	do	29.37	ENE	S, 9	SSW	S, 9	ENE-S-WSW.
Pres. Roosevelt, Am. S. S.	Cobh	New York	49 54 N.	24 54 W.	Sept. 9	2p, 9	Sept. 10	29.27	SW	W, 8	W	W, 8	SW-W.
Statendam, Du. S. S.	New York	Rotterdam	50 46 N.	26 31 W.	do	4p, 9	do	29.01	WSW	WSW, 9	W	W, 10	WSW-W.
Emile Francqui, Belg. S. S.	Antwerp	New York	50 39 N.	23 47 W.	do	6p, 9	Sept. 9	29.24	SW	SW, 8	W	SW, 8	SW-W.
Spidoleine, Belg. M. S.	do	do	42 18 N.	55 43 W.	Sept. 12	8a, 11	Sept. 12	29.89	ENE	W, 4	NNE	ENE, 9	S-W.
Adria, Ger. M. S.	Danzig	Baltimore	58 42 N.	8 48 W.	Sept. 11	—, 11	Sept. 13	29.60	SSW	SSW, 9	SSW	S, 10	None.
Scanpenn, Am. S. S.	New York	Copenhagen	48 10 N.	50 00 W.	do	2a, 12	Sept. 12	29.80	NNW	N, 8	NW	NNW, 9	WNW-N-NW.
Europa, Ger. S. S.	Cherbourg	New York	48 48 N.	27 12 W.	Sept. 12	7a, 12	do	29.51	S	SSW, 8	WSW	S, 9	S-SSW-NW.
Adria, Ger. M. S.	Danzig	Baltimore	55 30 N.	27 54 W.	Sept. 14	10a, 15	Sept. 14	29.67	SW	W, 2	SW	SW, 9	None.
Cavina, Br. S. S.	Avonmouth	Barbados	14 32 N.	58 24 W.	Sept. 15	8p, 15	Sept. 16	[2] 29.93	ENE	NNE, 7	NW	NNE, 7	NE-N.
Volendam, Du. S. S.	New York	Rotterdam	50 07 N.	6 22 W.	Sept. 17	4a, 17	Sept. 17	29.50	S	S, 8	S	S, 8	None.
Yaka, Am. S. S.	Havre	PanamaCity, Fla.	35 00 N.	49 30 W.	Sept. 18	2p, 18	Sept. 18	30.10	SW	WSW, 11	WSW	WSW, 11.	SW-WSW.
Gripsholm, Swed. M. S.	Gothenburg	New York	53 55 N.	35 38 W.	Sept. 22.	Mdt. 24.	Sept. 25	29.27	WNW	WNW, 10	NW	WNW, 10	WSW-WNW-NW.
Caledonia, Br. S. S.	Glasgow	Boston	54 18 N.	26 54 W.	Sept. 24	9a, 25	Sept. 26	28.94	W	SW, 10	W	SW, 10	SW-W.
Lustrous, Br. S. S.	Preston	Port Arthur.	44 45 N.	23 09 W.	Sept. 25	6p, 25	Sept. 25	[2] 29.32	SW	WSW, 11	NNW	NW, 12	WSW-NW.
Caledonia, Br. S. S.	Glasgow	Boston	[1] 51 05 N.	41 02 W.	Sept. 27	11a, 27	Sept. 27	29.83	NNW	WNW, 7	NW	NW, 9	Steady.
Blankaholm, Swed. M. S.	Kotka, Finland.	Portland, Maine.	57 21 N.	23 30 W.	do	Mdt., 27.	Sept. 28	28.15	SSE	SSE, 4	WNW	SSE, 9	SSE-WSW.
Slemmestad, Nor. M. S.	Copenhagen	Montreal	59 19 N.	23 47 W.	do	Noon, 28.	Sept. 29	28.64	SSE	ESE, 6	NW	SSE, 9	SE-NE-N.

[1] Position approximate.
[2] Barometer uncorrected.

OCEAN GALES AND STORMS, SEPTEMBER 1934—Continued

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Direction and highest force of wind	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH PACIFIC OCEAN			° ′	° ′				Inches					
Nitro, U. S. N. Auxiliary	San Diego	Balboa	10 48 N.	87 48 W.	Sept. 1	6p, 1	Sept. 1	29.79	NE	E, 4	NE	NE, 8	E-NE.
Amagisan Maru, Jap. S. S.	Los Angeles	Yokohama	47 35 N.	177 35 E.	Sept. 3	3a, 3	Sept. 3	29.09	NW	W, 7	NNW	NNW, 8	SW-W.
Golden Dragon, Am. S. S	San Francisco	do	45 25 N.	170 35 W.	do	6p, 3	Sept. 4	29.39	WSW	WSW, 8	W	W, 8	SW-W.
Nichiyo Maru, Jap. M. S	Yokohama	Los Angeles	42 50 N.	160 40 E.	Sept. 9	10a, 8	Sept. 10	29.40	NW	N, 7	WNW	NW, 8	S-N-W.
Golden Dragon, Am. S. S	San Francisco	Yokohama	45 16 N.	167 52 E.	do	2a, 9	Sept. 9	29.14	NW	S, 7	NW	NW, 9	S-W-NW.
Fernmoor, Nor. M. S	Philippine Islands.	Los Angeles	40 20 N.	172 00 E.	Sept. 8	Noon 9	do	29.61	SE	WNW, 8	WNW	S, 9	SSW-WNW.
Ethan Allen, Am. S. S	Los Angeles	Shanghai	31 00 N.	136 55 E.	do	6a, 9	do	29.65	SSE	S, 8	S	SSE, 8	SSE-S.
Tosari, Du. M. S	Philippine Islands.	Los Angeles	41 18 N.	177 25 E.	Sept. 9	7p, 9	do	29.40	S	S, 8	S	S, 9	S-W-WNW.
San Angelo, Am. S. S	Los Angeles	Balboa	15 35 N.	100 22 W.	Sept. 10	4p, 10	Sept. 10	29.70	ESE	ESE, 8	ESE	ESE, 8	
Seattle, Am. S. S	Tacoma	Yokohama	50 30 N.	174 54 W.	Sept. 9	Noon, 11	do	29.76	ESE	SSW, 6	SE	SE, 8	SE-SSW-W.
Santos Maru, Jap. M. S	Los Angeles	do	40 21 N.	155 32 E.	Sept. 15	9a, 15	Sept. 15	29.45	WNW	WSW, 7	NW	NW, 8	SW-WNW-NW.
Sanyo Maru, Jap. M. S	do	do	42 52 N.	159 37 E.	do	2p, 15	do	29.17	NW	SSW, 6	NNW	N, 10	SE-SSW.
Ogura Maru, Jap. M. S	Yokohama	Los Angeles	41 24 N.	165 15 E.	Sept. 16	Mdt, 15	Sept. 16	29.00	N	WSW, 3	N	N, 8	SW-N.
Illinois, Am. S. S	Philippine Islands.	San Francisco	45 22 N.	172 45 W.	Sept. 17	4a, 18	Sept. 18	29.00	E	S, 3	W	W, 9	S-W.
Ogura Maru, Jap. M. S	Yokohama	Los Angeles	42 45 N.	174 49 W.	Sept. 19	Noon, 19	Sept. 19	29.40	S	SSW, 8	SSW	SSW, 8	SSE-SSW.
Ward, Am. M. S	Shanghai	do	41 56 N.	164 25 E.	do	4a, 19	do	29.45	E	E, 7	ENE	E, 8	ESE-NE.
Edgar F. Luckenbach, Am. S. S.	Los Angeles	Balboa	20 42 N.	107 25 W.	Sept. 18	1a, 19	do	29.43	ESE	SE, 10	SSE	SE, 12	ESE-SE.
Pennsylvania, Am. S. S	Balboa	San Diego	21 58 N.	108 45 W.	Sept. 19	Noon, 19	do	29.74	ESE	ESE, 7	NNE	ESE, 8	ESE-NE.
Virginia, Am. S. S	Los Angeles	Balboa	21 59 N.	107 51 W.	do	3p, 19	do	29.66	ENE	E, 9	SE	E, 9	E-SE.
Malolo, Am. S. S	do	do	21 03 N.	109 16 W.	do	8p, 19	do	29.22	NE	NW, 9	S	NW, 9	NE-NW-S.
City of Vancouver, Br. S. S.	Tsingtao	Vancouver	47 20 N.	179 32 W.	do	3p, 19	Sept. 20	28.89	ENE	NNW, 9	WNW	NW, 10	NE-NNW-NW.
Point Clear, Am. S. S	Balboa	Los Angeles	23 00 N.	110 20 W.	Sept. 18	5a, 20	do	29.68	E	NE, 6	NE	ENE, 9	
Mauna Ala, Am. S. S	Los Angeles	Balboa	22 23 N.	109 14 W.	Sept. 19	9a, 20	do	28.81	N	NNE, 11	SSE	NE, 12	NE-N-WSW.
Iowan, Am. S. S	Balboa	Los Angeles	21 — N.	108 30 W.	do	8a, 20	do	29.61	SW	S, 9	SSE	S, 9	None.
Pres. Monroe, Am. S. S	do	do	22 50 N.	110 21 W.	Sept. 20	9p, 20	Sept. 21	29.32	SSE	E, 10	N	NE, 11	SSE-E-NE.
Lossiebank, Br. M. S	do	do	22 12 N.	110 22 W.	do	3a, 21	do	29.63	S	S, 7	WNW	SW, 9	S-W.
Bonneville, Nor. M. S	Los Angeles	Kobe	32 40 N.	140 50 E.	Sept. 21	4p, 21	do	29.65	S	S, 8	SSW	S, 9	S-SSW.
Hiye Maru, Jap. M. S	Yokohama	Vancouver	40 19 N.	151 12 E.	Sept. 22	10a, 22	Sept. 22	29.31	SW	SW, 8	NNW	NW, 9	SW-NW-N.
Ward, Am. M. S	Shanghai	Los Angeles	41 18 N.	163 20 W.	Sept. 23	11a, 23	Sept. 23	29.10	SSE	SSW, 8	W	SW, 8	S-SSW-WSW.
Tahchee, Br. S. S	Yokohama	do	42 30 N.	170 00 E.	Sept. 22	3a, 23	do	28.99	ESE	ESE, 9	NE	E, 9	SE-NE.
Do	do	do	43 00 N.	178 00 W.	Sept. 24	6p, 24	Sept. 24	29.24	S	S, 8	WNW	WNW, 8	SSE-WNW.
City of Vancouver, Br. S. S.	Tsingtao	Vancouver	48 09 N.	160 30 W.	Sept. 23	2a, 24	do	28.47	ESE	SSE, 9	W	W, 10	SE-SSE-S.
Wisconsin, Am. S. S	Otaru	San Francisco	45 00 N.	172 40 W.	Sept. 24	Mdt, 24	Sept. 25	29.17	S	SW, 8	W	S, 9	S-SW-W.
Silverguava, Br. M. S	Philippine Islands.	Portland, Oreg.	16 32 N.	127 21 E.	Sept. 28	4p, 28	Sept. 29	29.61	NNE	NE, 8	SE	E, 10	NE-E.
San Diego Maru, Jap. M. S.	Yokohama	Los Angeles	42 12 N.	161 45 E.	Sept. 27	4a, 28	Sept. 27	29.65	SE	SW, 5	SE	SE, 8	SE-SW-NE.
Arthur J. Baldwin,[3] Am. S. S.	Nome	Seattle	51 42 N.	136 50 W.	Sept. 29	—, 29	Sept. 29	29.65	NNE	NNE, 10	WNW	NNE, 10	NNE-WNW.
Pres. Jackson, Am. S. S	Yokohama	Victoria, B. C	50 00 N.	145 18 W.	Sept. 30	3a, 30	Sept. 30	29.94	S	S, 6	S	S, 8	S.

[3] G. M. N. data only.

NORTH PACIFIC OCEAN, SEPTEMBER 1934

By WILLIS E. HURD

Atmospheric pressure.—The pressure situation over northern waters of the North Pacific Ocean showed considerable change from that during August: In September the Aleutian cyclone was well established, central in the Bering Sea, with an average pressure of 29.65 inches at St. Paul. Both here and at Dutch Harbor the mean barometer was slightly below the normal. East of the Peninsula of Alaska abnormally high pressures for the month prevailed.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, North Pacific Ocean, September 1934, at selected stations*

Station	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	Inch	Inches		Inches	
Point Barrow	30.11	+0.21	30.86	11	29.44	6
Dutch Harbor	29.70	−.06	30.20	9	29.14	24
St. Paul	29.65	−.06	30.04	2	29.22	25
Kodiak	29.90	+.19	30.24	21, 22	29.50	5
Juneau	30.03	+.11	30.43	22	29.53	17
Tatoosh Island	30.05	+.05	30.38	14	29.59	22
San Francisco	29.90	−.04	30.13	25	29.68	8
Mazatlan	29.83	+.01	29.92	2	29.74	11
Honolulu	29.98	−.02	30.06	30	29.84	12
Midway Island	29.96	−.05	30.12	30	29.72	22, 23
Guam	29.85	+.02	29.98	22	29.76	14
Manila	29.74	−.08	29.82	15,21,27	29.54	12
Hong Kong	29.72	--------	29.89	22	29.51	6
Naha	29.80	+.04	30.14	28	28.98	19
Chichishima	29.96	+.10	30.12	25	29.80	5
Nemuro	29.93	--------	30.30	4	29.58	11

NOTE.—Data based on 1 daily observation only, except those for Juneau, Tatoosh Island, San Francisco, and Honolulu, which are based on 2 observations. Departures are computed from best available normals related to time of observation.

The easternmost third of the ocean, north of the tropics, was for the most part the seat of well-established anticyclone conditions; and few depressions of moment occurred, even in extreme northeastern waters.

Low pressure continued in the Far East.

Cyclones and gales.—A definite increase in storminess over that of August occurred along the central and western parts of the northern steamship routes during September. While some gales resulted from the eastward movement of continental cyclones, the majority were due to conditions arising from the considerable deepening of cyclones connected with the early autumn surges of the Aleutian low-pressure system. West of the one hundred eightieth meridian the majority of the gales occurred prior to the 21st of the month; east of that meridian very few gales occurred earlier than the 19th.

On about 20 days of the month, gales were reported along some portion of the routes north of the thirty-ninth parallel. While in several instances the force did not exceed 8, that of a fresh gale, yet on at least 8 days the force rose to 9 (strong gale), or to 10 (whole gale).

Only one high latitude Low of consequence formed over extreme northeastern waters. This was of brief duration and caused gales over a comparatively small area on the 29th and 30th—that of the 29th, of force 10, occurring near 52° N., 137° W.

On the 8th and 9th, gales of force 8–9 were experienced over a considerable area between 160° E. and the one hundred eightieth meridian, with lowest pressure almost down to 29 inches.

On the 15th a cyclone with lowest pressure about 29 inches appeared, central near 41° N., 165° E.; and on that

and the following day caused gales of force 8-10 in the neighborhood. The storm area moved eastward and northward; and on the 18th was closely followed by another low-pressure area of slightly greater intensity which, on the 19th to 21st, lay first to the southward of and then over the central Aleutians, with lowest pressure 28.88 inches, and maximum wind force of 10.

On the 23d gale conditions set in near 41° N., 163° W., with barometer depressed to 29.10 inches. On the 24th the pressure dropped to 28.47 inches—the lowest reading of the month in high latitudes—near 48° N., 160½° W. The gale field was of great extent on this date, with wind-forces up to 10. Thenceforward until the end of the month the cyclone fluctuated with lessened intensity north and south of the eastern Aleutians and south of the Peninsula of Alaska, with no gales exceeding force 8 reported as occurring within its boundaries.

Typhoons.—One major typhoon of disastrous proportions, and five lesser typhoons occurred in the Far East during September. Rev. Fr. Bernard F. Doucette, S. J., of the Philippine Weather Bureau, in an accompanying note, has discussed these storms; and it remains for the present report only to add a few comments with reference to the most important typhoon of the month which, according to some estimates, caused more material damage in southern and central Japan than any recent natural agency other than the great earthquake of 1923. In addition to the losses elsewhere enumerated, the partial destruction of the islands' rice crop through hurricane winds and rain must be further mentioned as a national calamity.

During the passage of the typhoon over Shikoku Island on September 21, Kochi Observatory recorded a pressure reading of 684 millimeters (26.93 inches), which is the lowest sea-level barometer reading ever recorded at an official observatory.

Cyclone off the Mexican west coast.—On September 16 a depression was forming at some distance south of Acapulco. It advanced in a northwesterly direction, and by the 18th was apparently central about 125 miles south of Manzanillo. Up to this time the depression seems to have given no evidence of severity, except that at 9 a. m. on the 18th the American S. S. *Mauna Kea*, near 20½° N., 108°10′ W., encountered very high short swells which pitched the ship violently and submerged her hatches. At 8 p. m. on the 18th, however, the American S. S. *Edgar F. Luckenbach*, southbound, encountered winds of fresh gale force in approximately 21° N., 108° W. Gales thereafter continued to be experienced by the ship until near noon of the 19th, reaching hurricane force at times between 1 and 5 a. m., with lowest barometer 29.43 at 1 a. m. in 20°42′ N., 107°25′ W., and southeasterly winds throughout.

During the 19th, 20th, and 21st the cyclone passed rather slowly northward just outside the mouth of the Gulf of California, accompanied by strong gales to hurricane velocities over a narrow region between Cape Corrientes and southern Lower California. The lowest barometer reported was 28.81 inches, read on the American S. S. *Mauna Ala*, in 22°23′ N., 109°14′ W., at 8 p. m. of the 20th, accompanied by a northeast gale of hurricane force. By morning of the 22d the cyclone, diminished to a shallow Low, lay just outside Lower California near 24° N., whence it moved northward and apparently disappeared over the peninsula.

A minor disturbance appeared near Acapulco on the 10th and off Manzanillo on the 11th. Reports from the northeastern edge of the disturbance show a gale of force 8 southwest of Acapulco on the 10th and a gale of force 7 near Cape Corrientes on the 11th.

Fog.—Fog lessened materially this month as compared with August. It was observed on the 21st and 22d at the entrance of the Gulf of California; on 8 days off the California coast; and on 4 days off the Washington and Oregon coasts. Along the entire length of the upper steamship routes, scattered fogs occurred on 1 to 4 days in most of the 5° squares.

TYPHOONS IN THE FAR EAST DURING SEPTEMBER 1934

By BERNARD F. DOUCETTE, S. J.

There were six typhoons during September 1934 over the regions of the Far East. A large and very severe typhoon crossed Balintang Channel, passing close to and south of Basco, early in the month. Two typhoons moved simultaneously toward Naha, then combined (or else one vanished); but the next day found an intense typhoon which moved rapidly north and caused much destruction in Japan September 21. Toward the end of the month a typhoon crossed northern Luzon, causing considerable damage.

First typhoon, September 1-11, 1934.—About 700 miles east of the archipelago this typhoon appeared on the weather map of September 1. It moved west-northwest, changing to northwest, crossing the Balintang Channel and then recurving to the northeast when it reached the northern part of the Formosa Channel. The positions of its center are given below.

September 1, 2 p. m.: Latitude 14°.30 N., longitude 135° E.
September 2, 6 a. m.: Latitude 15° N., longitude 133° E.
September 3, 6 a. m.: Latitude 15°.30 N., longitude 130° E.
September 4, 6 a. m.: Latitude 17° N., longitude 125° E.
September 5, 6 a. m.: Latitude 20°.15 N., longitude 122° E.
September 6, 6 a. m.: Latitude 23° N., longitude 120°.30 E.
September 7, 6 a. m.: Latitude 26° N., longitude 122° E.
September 8, 6 a. m.: Latitude 29° N., longitude 125° E.
September 9, 6 a. m.: Latitude 35° N., longitude 134° E.
September 10, 6 a. m.: Latitude 44° N., longitude 144° E.
September 11, 6 a. m.: Latitude 47° N., longitude 147° E.

This typhoon passed close to and south of Basco during the forenoon of September 5; 704.38 millimeters (27.731 inches) was recorded as a minimum pressure at Basco, September 5, 6:35 a. m., with southeast winds, force 5. Winds from east-northeast, force 11, were recorded before the minimum; and from the south, force 10, after the minimum.

The winds and the rains caused great destruction over the northern regions of the archipelago, floods washing away bridges, roads being inundated, and crops destroyed.

Second typhoon, September 11-16, 1934.—This typhoon formed in the Pacific, and first gave indications of its existence on the weather map September 11, 2 p. m., its location being latitude 17° N., longitude 128° E. It moved west-northwest to latitude 18° N., longitude 125° E. (Sept. 12, 6 a. m.), continued west-northwest, crossing Balintang Channel as a depression, and increased in energy September 13 (latitude 19° N., longitude 120° E.). The next day it was close to and south of Pratas at latitude 20° N., longitude 116° E. On the 15th it was over the island of Hainan and it disappeared over Indo-China, September 16.

Third and fourth typhoons, September 13-22, 1934.—These two typhoons formed within 3 days of each other over the Pacific near the Caroline Islands. They moved over different paths to the region south of Naha, where both combined into one severe typhoon, or else one increased in intensity while the other vanished. The single typhoon of September 20 moved rapidly northward

to Japan, where it caused great destruction to life and property.

The determination of the positions given below is quite accurate, due to observations received from the U. S. S. *Gold Star*, en route Guam to Manila, S. S. *Silverbelle*, and S. S. *Foylebank*, both en route San Francisco to Manila. All three passed through San Bernardino Strait on their way to Manila. Officers on these ships were certain of the existence of the typhoons, which were quite far from the ships. The observatory received daily reports from the *Gold Star* which enabled the position of the third typhoon to be given with the daily forecasts. The positions of the fourth typhoon were not known until the observations from the ships were obtained on their arrival at Manila. The positions of the third September typhoon were as follows:

September 13, 6 a. m.: Latitude 10° N., longitude 143° E.
September 14, 6 a. m.: Latitude 11° N., longitude 142° E.
September 15, 6 a. m.: Latitude 12° N., longitude 135° E.
September 16, 6 a. m.: Latitude 13° N., longitude 132°.30 E.
September 17, 6 a. m.: Latitude 14° N., longitude 131° E.
September 18, 6 a. m.: Latitude 16° N., longitude 126° E.
September 19, 6 a. m.: Latitude 20° N., longitude 124° E.

The U. S. S. *Gold Star* was in the northwestern sector of this typhoon on its journey to Manila.

The fourth September typhoon appeared on the weather map September 15, 2 p. m. From the variations of wind and pressure at Guam, it seemed that a disturbance of some kind was passing to the southwest of the island. It was assumed that a typhoon was moving northwest, but no determinations of the center could be made until the S. S. *Silverbelle* and S. S. *Foylebank* arrived at Manila when the following positions were determined:

September 16, 6 a. m.: Latitude 13°.30 N., longitude 140° E.
September 17, 6 a. m.: Latitude 17°.30 N., longitude 135°.30 E.
September 18, 6 a. m.: Latitude 22° N., longitude 131°.30 E.
September 19, 6 a. m.: Latitude 24° N., longitude 129° E.

Thus, on September 19 two typhoons appeared, one centered about 180 miles northeast of Aparri, moving north, the other about 550 miles northeast of Aparri, moving northwest. The next day, September 20, only one typhoon appeared, about 120 miles south of Naha. It is difficult to determine whether the two typhoons combined into one, or one vanished while the other increased in intensity. It is assumed here that the so-called third typhoon vanished while the fourth continued, the following being the positions on the next few days:

September 20, 6 a. m.: Latitude 25° N., longitude 128° E.
September 21, 6 a. m.: Latitude 33° N., longitude 134° E.
September 22, 6 a. m.: Latitude 42° N., longitude 150° E.

It will be noticed, if these positions are plotted, that the typhoon recurved to the northeast on September 20.

This typhoon caused great destruction to life and property as it passed over Japan, September 21. The strong winds and heavy rains, together with large waves from the sea, did much harm in the Osaka prefecture. From Manila newspapers of September 27, the following report from Japanese authorities was quoted: 2,523 people were killed, 13,184 people were injured, 656 people missing; 34,262 buildings were destroyed and 40,274 buildings seriously damaged; 10,931 vessels of various sizes were wrecked or sunk. Of the dead, 1,665 were in the Osaka prefecture, which suffered most. Rain and disease intensified the suffering of the homeless, approximately 200,000, in the Osaka prefecture.

Fifth typhoon, September 22–29.—This typhoon first appeared southwest of Yap, September 22, moved northwest for 3 days, then crossed Balintang Channel September 25–26, moving west-northwest, changing to west-southwest in the China Sea. It entered Indo China September 28. The positions of the center day by day are given below:

September 22, 2 p.m.: Latitude 8° N., longitude 137° E.
September 23, 6 a.m.: Latitude 10° N., longitude 135° E.
September 24, 6 a.m.: Latitude 13° N., longitude 131° E.
September 25, 6 a.m.: Latitude 18° N., longitude 125° E.
September 26, 6 a.m.: Latitude 20° N., longitude 119° E.
September 27, 6 a.m.: Latitude 18° N., longitude 113° E.
September 28, 6 a.m.: Latitude 17° N., longitude 108° E.

Sixth typhoon, September 27–October 2.—This typhoon formed September 26 south of Yap and was definitely located September 27. It moved northwest, changing to west-northwest for a day, and then moved directly for northern Luzon. It crossed the Cagayan Province south of Aparri and was in the China Sea, September 30, where it moved westward to Indo China.

September 27, 6 a.m.: Latitude 7° N., longitude 137° E.
September 28, 6 a.m.: Latitude 12° N., longitude 125° E.
September 29, 6 a.m.: Latitude 16° N., longitude 124° E.
September 30, 6 a.m.: Latitude 18° N., longitude 119° E.
October 1, 6 a.m.: Latitude 18°.30 N., longitude 113° E.
October 2, 6 a.m.: Latitude 21° N., longitude 108°.30 E.

This typhoon caused much damage over the northern part of the archipelago, but it is impossible to give estimates because another typhoon passed over the same course on October 4, which typhoon will be described in the report for next month. An interesting aspect of this typhoon was the heavy winds experienced at Manila (force 6 and 7 from the southwest) but light winds (force 3) at stations close to the center, as the typhoon crossed the island September 29.

CLIMATOLOGICAL TABLES

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, September 1934

[For description of tables and charts, see Review, January, p. 37]

Section	Temperature: Section average	Temperature: Departure from the normal	Monthly extremes: Station	Highest	Date	Station	Lowest	Date	Precipitation: Section average	Departure from the normal	Greatest monthly: Station	Amount	Least monthly: Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	75.1	−0.6	Ozark	99	28	Valley Head	48	5	2.02	−1.30	Madison	5.30	Marion	0.35
Arizona	74.2	−.4	Quartzsite	116	3	Williams	11	26	.58	−.56	Oracle	3.19	14 stations	.00
Arkansas	71.3	−3.1	4 stations	100	[1] 11	2 stations	37	17	5.46	+2.08	Sunset	14.13	Magnolia	1.44
California	68.9	+1.4	Greenland Ranch	119	4	Twin Lakes	7	25	.33	−.14	Bowman Dam	2.96	32 stations	.00
Colorado	57.1	−.7	Las Animas	99	[1] 1	Pearl	6	27	1.11	−.19	Crested Butte	4.04	Auldhurst	T
Florida	79.7	+.2	Hastings	98	30	Cottage Hill	53	6	4.59	−2.15	Everglades	12.95	Garniers	.58
Georgia	76.4	+.8	3 stations	99	[1] 27	Blairsville	43	6	2.57	−1.10	Fair View	7.12	Columbus	.40
Idaho	55.5	−1.2	Cambridge	103	6	Prairie	10	26	.56	−.44	Malad	2.63	4 stations	.00
Illinois	65.2	−1.8	Mascoutah	95	1	6 stations	35	27	6.64	+3.01	Beardstown	10.33	Streator	3.59
Indiana	66.7	−.5	Butlerville	96	24	Marengo	34	28	5.67	+2.26	La Porte	10.19	Leavenworth	3.00
Iowa	61.0	−2.6	2 stations	94	[1] 10	Inwood	25	21	5.07	+1.26	Grundy Center	8.94	Omaha, Nebr	2.32
Kansas	65.2	−4.4	Ashland	102	12	3 stations	26	26	4.18	+1.38	Oswego	15.61	Healy	.55
Kentucky	69.2	−1.3	2 stations	95	[1] 4	Taylorsville	39	28	4.82	+1.85	Paducah (near)	10.99	Whitesburg	1.79
Louisiana	76.8	−1.2	3 stations	99	[1] 11	St. Joseph	44	18	3.57	−.34	Lafayette	8.47	New Orleans No. 1	1.16
Maryland-Delaware	68.7	+.9	Salisbury, Md	92	11	2 stations	36	[1] 28	9.33	+6.10	Washington, D. C	17.45	Friendsville, Md	3.12
Michigan	60.6	+.4	Caro	92	15	Dukes	23	23	5.14	+1.91	St. Joseph	10.12	Lansing	2.21
Minnesota	54.8	−4.2	Beardsley	93	13	Pokegama Falls	15	21	3.41	+.49	Reeds	9.07	Argyle	.67
Mississippi	75.0	−.9	2 stations	100	[1] 12	Batesville	44	[1] 17	4.00	+.90	Greenville	7.26	Biloxi	1.02
Missouri	65.6	−3.6	do	95	[1] 1	2 stations	32	27	7.39	+3.25	Farmington	15.09	Poplar Bluff	4.07
Montana	51.6	−3.0	Kenilworth (near)	98	4	Cut Bank	−4	25	1.13	−.26	Lytle	2.99	Bridger	.16
Nebraska	59.7	−4.1	9 stations	95	[1] 12	Harrison	10	26	2.51	+.37	Auburn	7.73	Bridgeport	.34
Nevada	63.3	+2.4	Las Vegas	110	[1] 4	2 stations	9	26	.27	−.15	Lewers Ranch	1.70	12 stations	.00
New England	63.4	+3.0	4 stations	90	[1] 8	Chelsea, Vt	29	1	6.93	+3.19	Norwalk, Conn	15.64	East Wareham, Mass.	1.36
New Jersey	67.3	+1.4	Camden	91	9	2 stations	35	1	9.00	+5.44	Little Falls	13.42	Camden	4.02
New Mexico	64.0	−.4	Carlsbad	105	[1] 2	Lake Alice	11	26	.91	−.69	Jemez Springs	4.27	7 stations	.00
New York	64.3	+3.0	Delhi	96	26	Dannemora	30	28	5.38	+1.96	Flushing	15.06	Penn Yan	1.78
North Carolina	72.5	+1.5	Albemarle	97	11	Banners Elk	34	2	6.12	+2.13	Hatteras	14.96	Waynesville	1.51
North Dakota	52.4	−4.0	Arnegard	95	11	Bowman	9	26	.96	−.69	Forman	2.22	Arnegard	.13
Ohio	67.8	+2.2	Circleville	95	24	Mount Vernon (near)	31	28	3.82	+.83	Lake Milton	8.53	Marion	1.88
Oklahoma	71.1	−3.1	Buffalo	101	12	Boise City	29	26	6.13	+3.05	Holdenville	12.90	Boise City	1.23
Oregon	57.4	−.1	Riddle	107	2	Fremont	5	25	.63	−.60	Kinzua	4.26	2 stations	.00
Pennsylvania	66.4	+2.3	Franklin	94	25	Kylertown	31	28	6.58	+3.12	Gettysburg	15.13	Beaver Dam	2.41
South Carolina	75.7	+1.2	6 stations	96	[1] 5	2 stations	48	[1] 2	3.55	−.55	Ceasers Head	12.59	Edgefield	.76
South Dakota	57.1	−4.3	Dowling	98	12	Lead	12	26	2.11	+.41	Flandreau	7.43	McLaughlin	.18
Tennessee	70.8	−.6	5 stations	95	[1] 11	2 stations	42	[1] 5	4.35	+1.25	Ashwood	7.93	Kingston	1.76
Texas	77.2	−.2	3 stations	105	[1] 2	Dalhart	35	26	2.79	−.08	Beaumont	12.05	3 stations	.00
Utah	60.7	+.2	St. George	105	2	Soldier Summit	13	27	.46	−.56	Wendover	1.93	do	.00
Virginia	70.0	+1.3	Diamond Springs	93	10	Burkes Garden	36	2	6.83	+3.75	Washington, D. C	17.45	Mendota	2.14
Washington	57.0	−1.2	Wahluke	104	4	Newport	11	25	1.77	−.06	Mount Baker Lodge	8.69	White Swan	.16
West Virginia	69.0	+2.5	4 stations	94	25	2 stations	33	3	4.19	+1.26	Martinsburg	7.19	Bens Run	1.86
Wisconsin	58.0	−2.3	Fond du Lac	90	25	Mellen	22	30	6.05	+2.37	Rest Lake	10.44	Green Bay	1.91
Wyoming	51.3	−3.2	Pine Bluffs	96	12	Kirtley	6	26	1.14	−.02	Rockypoint	3.20	Kendall	.10
Alaska (August)	54.0	.0	2 stations	90	[1] 5	Allakaket	20	22	3.97	+.58	Cordova	12.80	Barrow	T
Hawaii	75.9	+1.3	do	95	[1] 1	Kanalohuluhulu	48	3	7.27	+1.27	Puhonua	31.40	2 stations	.00
Puerto Rico	78.5	−.6	San German	96	15	Guineo Reservoir	49	4	6.70	−1.34	Maricao	16.40	Mona Island	1.30

[1] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, September 1934*

[Compiled by Annie E. Small]

District and station	Elevation of instruments: Barometer above sea level	Thermometer above ground	Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Departure from normal	Days with 0.01, or more	Wind: Total movement	Prevailing direction	Maximum velocity: Miles per hour	Direction	Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							64.2	+3.3										87	5.18	+2.1										6.9		
Eastport	76	67	85	30.08	30.17	+0.14	58.4	+2.6	73	10	64	47	29	53	16	56	54	90	3.65	+0.9	12	5,504	sw.	32	se.	18	9	4	17	6.7	0.0	0.0
Greenville, Me	1,070	6	40	28.99	30.15		59.2		82	26	67	38	29	51	29				4.25		14	3,057	se.	21		27	7	8	15		.0	.0
Portland, Me	103	82	117	30.02	30.14	+.09	62.8	+3.2	81	9	69	48	14	57	22	59	57	86	5.77	+2.7	16	5,672	s.	33	se.	9	12	4	14	5.9	.0	.0
Concord	289	60					63.2	+3.9	83	26	72	41	1	54	31				6.74	+3.3	12		nw.				8	7	15		.0	.0
Burlington	403	11	48	29.66	30.09	+.03	63.6	+3.3	84	26	72	42	30	56	29				4.05	+.0	11	7,146	s.	32	s.	27	9	7	14	6.3	.0	.0
Northfield	876	12	60	29.19	30.13	+.07	61.0	+4.9	82	25	71	36	1	51	35	57	55	87	3.45	+.4	13	5,090	s.	32	sw.	27	4	8	18	7.6	.0	.0
Boston	124	336	360	29.99	30.13	+.06	64.6	+1.4	81	9	70	52	2	59	20	61	60	88	5.67	+2.5	15	8,277	e.	45	se.	9	4	10	16	7.3	.0	.0
Nantucket	12	14	90	30.10	30.11	+.03	66.8	+4.0	81	7	73	54	29	61	19	63	62	90	3.37	+.9	14	8,853	e.	30	sw.	30	8	8	14	6.7	.0	.0
Block Island	26	11	46	30.08	30.10	+.02	66.4	+3.0	76	10	71	56	1	62	14	64	62	91	2.38	−.3	13	9,313	e.	40	se.	8	6	9	15	6.8	.0	.0
Providence	160	215	251	29.95	30.12	+.05	66.4	+3.2	84	9	74	47	2	59	27	62	60	84	4.13	+1.0	17	6,882	se.	43	se.	9	6	8	16	7.0	.0	.0
Hartford	159	70	104		30.11	+.04	66.0	+4.3	83	10	74	47	1	58	27				9.06	+5.6	16	4,254	s.				4	7	19		.0	.0
New Haven	106	74	153	30.00	30.11	+.04	66.5	+3.0	84	9	74	49	1	59	23	62	60	83	8.76	+5.2	13	6,216	n.	37	se.	8	4	7	19	7.4	.0	.0

TABLE 1.—*Climatological data for Weather Bureau stations, September 1934*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Middle Atlantic States							**69.5**	**+2.4**										**83**	**8.31**	**+5.1**										**6.9**		
Albany	97	107	115	30.01	30.11	+0.04	66.2	+3.1	85	26	75	47	1	58	27	61	59	82	5.82	+2.7	14	4,995	s.	23	s.	27	5	10	15	6.7	0.0	0.0
Binghamton	871	60	68	29.17	30.10	+.03	64.8	+3.5	84	4	74	40	28	55	34				6.02	+2.9	10	3,585	e.	18	sw.	27	2	8	20	8.0	.0	.0
New York	314	415	454	29.76	30.09	+.01	68.2	+1.4	83	9	74	51	19	62	20	63	60	81	10.19	+6.8	12	7,683	e.	65	n.	8	8	8	14	6.5	.0	.0
Bellefonte	1,050	5	42	28.98	30.08		63.4		82	4	73	39	28	54	32	59	58	87	6.14		14		se.				4	12	14	7.0	.0	.0
Harrisburg	374	94	104	29.69	30.08	.00	67.5	+1.7	84	9	75	49	19	60	24	62	59	80	8.96	+5.9	14	4,324	e.	20	w.	27	8	11	11	6.3	.0	.0
Philadelphia	114	123	367	29.98	30.10	+.02	70.8	+2.8	85	9	78	53	19	64	23	64	61	78	6.27	+3.1	15	7,438	e.	36	ne.	8	6	8	16	6.8	.0	.0
Reading	323	283	306	29.74	30.08		67.3	+1.0	84	4	75	48	19	60	29	62	60	82	8.03	+4.8	13	7,393	se.	35	e.	8	8	8	14	6.6	.0	.0
Scranton	805	72	104	29.24	30.10	+.03	65.8	+2.9	85	9	75	43	28	57	33	60	57	80	4.40	+1.2	14	3,911	n.	20	sw.	27	4	14	12	6.6	.0	.0
Atlantic City	52	37	172	30.03	30.09	+.02	69.6	+2.8	81	10	74	51	19	65	23	66	64	85	5.54	+2.9	12	10,224	e.	60	nw.	8	5	10	15	6.8	.0	.0
Sandy Hook	22	10	57	30.07	30.09		69.0		82	10	74	54	19	64	17	65	63	84	10.00	+6.6	14	8,576	e.	65	n.	8	6	9	15	7.0	.0	.0
Trenton	190	88	106	29.89	30.09		68.2	+1.3	85	9	76	48	19	60	27	63	61	84	10.49	+7.1	15	5,837	n.	35	n.	8	6	9	15	6.8	.0	.0
Baltimore	123	100	215	29.95	30.08	.00	71.3	+2.8	88	10	78	53	19	65	24	65	63	80	12.41	+9.0	13	6,642	ne.	32	se.	16	8	6	16	6.5	.0	.0
Washington	112	62	85	29.96	30.08	.00	70.6	+2.5	87	27	78	52	1	63	25	65	63	83	17.45	+14.2	15	4,010	nw.	23	nw.	27	7	7	16	6.6	.0	.0
Cape Henry	18	8	54	30.04	30.06		73.9	+2.1	88	27	78	65	27	69	23	70	68	86	7.25	+4.4	9	8,551	se.	38	ne.	8	4	9	17	7.2	.0	.0
Lynchburg	686	5		29.35	30.09	+.01	71.8	+2.8	91	10	82	48	2	61	32				7.37	+4.1	14		n.				5	21	4		.0	.0
Norfolk	91	170	205	29.98	30.08	+.02	74.6	+3.0	90	10	81	64	18	69	21	69	68	87	6.80	+3.6	12	7,840	ne.	30	s.	16	2	6	22	8.2	.0	.0
Richmond	144	11	52	29.94	30.08	+.01	72.3	+1.8	90	11	80	55	1	65	24	67	66	88	5.92	+2.7	13	4,956	ne.	21	s.	16	6	8	16	6.7	.0	.0
Wytheville	2,304	49	55		30.05	+.02	66.4	+2.8	83	11	77	45	2	56	35			84	5.45	+2.2	11	2,912	e.	20	w.	27	9	10	11		.0	.0
South Atlantic States							**76.2**	**+2.6**										**85**	**5.12**	**+0.8**										**5.9**		
Asheville	2,253	89	104	27.77	30.07	.00	69.4	+4.4	87	12	81	46	3	58	36	62	60	83	3.90	+.9	15	4,343	s.	18	s.	29	6	15	9	5.7	.0	0.0
Charlotte	779	63	86	29.24	30.06	−.01	74.8	+3.3	91	12	83	55	1	66	25	68	65	80	4.89	+1.9	7	4,310	ne.	18	sw.	4	6	14	10	6.1	.0	.0
Greensboro	886	6	56	29.13	30.08		71.6		89	12	81	49	1	63	27	66	65	91	8.75		15	4,762	ne.	34	n.	12	6	15	9	6.1	.0	.0
Hatteras	11	5	50	30.03	30.04	−.02	76.6	+2.1	85	30	81	68	27	72	14	73	72	85	14.96	+10.4	15	7,933	ne.	65	nw.	8	7	10	13	6.2	.0	.0
Raleigh	376	103	146	29.66	30.05	−.02	73.8	+2.7	91	11	81	55	1	66	25	69	67	87	6.12	+2.5	14	5,453	ne.	22	se.	12	4	9	17	7.4	.0	.0
Wilmington	72	73	107	29.98	30.05	.00	76.0	+2.9	88	28	82	61	1	70	21	72	70	89	7.06	+2.6	17	5,156	n.	27	w.	30	5	10	15	6.9	.0	.0
Charleston	48	11	92	29.99	30.04	.00	78.2	+1.6	91	17	84	63	1	72	20	73	72	85	4.04	−.5	7	6,624	s.	30	se.	15	3	15	12	6.4	.0	.0
Columbia, S. C.	351	41	57	29.68	30.05	.00	77.0	+2.5	91	11	86	58	1	68	25	70	68	82	1.97	−1.5	9	4,394	ne.	21	se.	14	6	18	6	5.3	.0	.0
Augusta	182	62	77	29.84	30.03	−.02	78.0	+2.7	92	7	88	60	1	68	28	70	68	78	2.04	−1.3	7	3,615	se.	18	ne.	14	6	19	5	5.2	.0	.0
Savannah	65	73	152	29.96	30.03	.00	79.4	+3.2	93	30	88	61	1	71	25	72	71	85	4.20	−1.2	9	5,983	n.	21	se.	14	10	13	7	5.1	.0	.0
Jacksonville	43	86	110	29.98	30.03	+.03	79.2	+.9	93	8	87	66	3	72	22	73	71	85	1.99	−5.4	9	4,716	e.	20	e.	13	10	16	4	4.7	.0	.0
Florida Peninsula							**81.4**	**+0.7**										**80**	**8.01**	**+0.9**										**6.0**		
Key West	22	10	64	29.94	29.96	+.02	82.4	+.2	91	4	88	72	21	77	17	77	75	79	6.72	.0	22	6,367	e.	21	sw.	15	4	18	8	5.9	.0	0.0
Miami	25	124	168	29.97	30.00	+.03	81.0	+.9	93	7	86	71	15	76	18	75	73	79	9.69	+1.4	20	6,373	e.	29	w.	15	1	16	13	7.2	.0	.0
Tampa	35	88	197	29.97	30.00	+.03	80.8	+.9	93	9	89	69	21	73	21	74	72	83	7.62	+1.2	13	6,421	e.	32	e.	11	11	12	7	4.8	.0	.0
Titusville	43	5	36	29.96	30.01		79.0		90	30	87	65	3	71	22				4.59		15		e.				8	16	6		.0	.0
East Gulf States							**75.9**	**+0.3**										**77**	**2.32**	**−1.9**										**4.4**		
Atlanta	1,173	128	135	28.83	30.05	.00	73.8	+1.4	89	11	83	54	5	64	25	65	62	73	4.68	+1.7	10	5,311	nw.	24	se.	22	11	13	6	4.8	.0	0.0
Macon	370	79	87	29.65	30.04	+.01	76.0	+1.2	92	12	87	57	3	65	31	68	65	77	2.14	−1.0	6	3,795	n.	15	sw.	4	9	18	3	4.5	.0	.0
Thomasville	273	49	58	29.76	30.04	+.03	78.0	+1.2	95	28	89	58	1	67	29	71	69	81	1.61	−3.3	9		e.				7	12	11		.0	.0
Apalachicola	35	11	51	29.98	30.02		79.1		90	4	86	68	1	72	20	72			3.76	−4.3	8		n.				11	13	6		.0	.0
Pensacola	56	149	185	29.97	30.03	+.04	77.4	−.6	87	10	84	64	6	71	19	71	68	77	.79	−4.5	5	7,158	ne.	25	e.	14	16	13	1	3.8	.0	.0
Anniston	741	9					73.0	+1.7	90	11	84	50	5	62	31				2.67	−1.0	6		sw.				17	8	5		.0	.0
Birmingham	700	11	48	29.29	30.04	+.01	74.0	−.8	90	24	84	54	5	64	28	66	63	78	1.53	−1.8	5	3,625	se.	24	sw.	12	11	13	6	4.5	.0	.0
Mobile	57	125	161	29.95	30.01	+.01	77.2	−.9	91	12	85	61	6	69	22	70	68	79	.95	−4.0	8	5,428	n.	26	se.	14	13	13	3	4.3	.0	.0
Montgomery	218	92	105	29.80	30.04	+.02	76.8	+.5	93	12	87	58	8	66	27	68	64	74	1.32	−1.7	6	3,824	n.	18	sw.	22	13	11	6	4.3	.0	.0
Meridian	375	67	92	29.64	30.03	+.01	74.9	+.4	94	12	86	54	5	64	30	67	65	80	3.63	+.7	9	3,206	e.	18	sw.	26	13	14	3	4.0	.0	.0
Vicksburg	247	65	73	29.77	30.02	.00	75.1	−1.2	92	13	85	55	17	66	27	66	64	76	3.64	+.8	11	4,682	se.	20	s.	28	13	9	8	4.7	.0	.0
New Orleans	53	76	84	29.96	30.01	+.03	79.1	−.1	91	29	86	66	5	72	20	72	69	78	1.16	−3.9	8	4,294	se.	27	se.	22	10	14	6	5.1	.0	.0
West Gulf States							**76.6**	**−0.5**										**74**	**4.71**	**+1.0**										**4.6**		
Shreveport	249	92	227	29.73	30.00	.00	77.0	+.1	94	13	87	58	17	66	30	67	62	69	1.51	−1.3	7	7,502	s.	36	ne.	29	16	10	4	3.8	.0	0.0
Bentonville	1,303	11	44	28.62	29.98	−.04	66.5	−2.4	88	19	78	43	27	56	32				7.12	+3.3	11	4,251	s.	20	n.	13	11	9	10		.0	.0
Fort Smith	457	79	94	29.50	29.98	−.03	70.8	−3.2	93	13	81	51	16	61	30	63	59	73	10.49	+7.5	11	5,577	e.	34	w.	3	15	8	7	4.6	.0	.0
Little Rock	357	94	102	29.63	30.00	−.03	72.1	−2.0	95	19	82	52	17	62	30	63	59	71	4.00	+.8	7	5,475	s.	21	w.	14	15	6	9	4.5	.0	.0
Austin	605	136	148	29.33	29.96		79.8	+1.5	96	1	90	56	17	69	34	69	64	68	1.07	−2.3	9	6,320	s.	25	s.	28	6	18	6	5.7	.0	.0
Brownsville	57	88	96	29.86	29.92		80.7	+.1	92	5	88	66	17	74	25	74	73	85	7.49	+2.0	13	6,633	se.	32	ne.	30	10	14	6	5.1	.0	.0
Corpus Christi	20	11	78	29.95	29.97	+.02	80.2	+.5	90	3	86	66	5	75	18	74	72	80	6.36	+1.9	12	7,641	se.	28	ne.	30	13	10	7	4.7	.0	.0
Dallas	512	220	227	29.42	29.96		75.8		95	2	86	54	16	66	30	66	60	66	6.07	+3.4	5	8,839	se.	36	se.	9	15	8	7	4.1	.0	.0
Fort Worth	670	106	114	29.28	29.98	−.01	76.8	−.1	98	2	88	55	16	66	35				4.90	+2.4	5	7,360	s.	30	se.	9	15	8	7	3.9	.0	.0
Galveston	54	106	114	29.93	29.99	+.01	79.8	−.3	87	1	84	67	16	76	13	73	71	77	3.04	−2.5	11	7,318	se.	25	n.	30	14	12	4	3.9	.0	.0
Houston	138	292	314	29.84	29.99		78.7	−.3	93	2	87	59	16	70	24				3.57	−.5	10	7,931	se.	29	ne.	30	10	13	7	4.8	.0	.0
Palestine	510	64	72	29.47	29.99	.00	76.2	−.8	95	2	86	54	16	66	30	68	65	76	3.74	+.8	8	5,461	s.	22	se.	11	10	12	8	4.8	.0	.0
Port Arthur	34	58	66	29.95	29.99		79.1		90	26	86	62	16	72	22	72	69	79	4.59	−.2	12	5,122	e.	31	nw.	3	12	13	5	4.4	.0	.0
San Antonio	693	242	301	29.23	29.93	−.03	80.2	+1.2	95	1	90	60	16	70	28	70	66	71	1.95	−1.1	7	8,312	se.	41	e.	10	6	15	9	5.4	.0	.0
Ohio Valley and Tennessee							**69.6**	**+0.8**										**78**	**4.16**	**+1.2**										**5.5**		
Chattanooga	762	71	214	29.25	30.05	−0.01	73.4	+1.2	92	11	84	55	5	63	29	65	62	77	2.81	−0.3	10	4,117	w.	27	nw.	12	11	17	2	4.4	0.0	0.0
Knoxville	995	66	84	29.01	30.05	−.01	72.8	+2.2	89	14	84	53	5	62	30	65	62	79	2.92	+.2	10	3,057	w.	17	w.	29	8	16	6	4.8	.0	.0
Memphis	399	78	86	29.59	30.01	−.02	72.4	−1.2	91	20	81	54	17	64	26	64	60	72	3.22	+.4	7	5,061	sw.	22	ne.	15	9	12	9	5.4	.0	.0
Nashville	546	168	191	29.48	30.06	.00	70.6	−1.2	88	20	80	52	18	61	29	63	60	77	4.52	+1.1	14	5,480	s.	33	nw.	11	4	13	13	6.6	.0	.0
Lexington	989	5																														
Louisville	525	188	234	29.47	30.05	−.01	69.4	−1.1	89	25	79	47	28	60	29	62	58	76	3.07	+.3	15	6,023	s.	31	n.	29	8	15	7	5.0	.0	.0
Evansville	431	76	116	29.56	30.03	−.03	68.7	−2.0	89	25	78	48	28	60	28	62	59	78	8.14	+4.8	16	5,637	s.	30	sw.	3	9	9	12	5.9	.0	.0
Indianapolis	822	194	230	29.16	30.04	−.02	66.5	−.4	89	25	76	45	27	57	27	60	56	74	4.54	+1.1	15	6,535	s.	31	n.	28	6	14	10	6.0	.0	.0
Terre Haute	575	96	129	29.40	30.01		66.6		88	25	76	46	27	57	29	60	58	81	7.08	+3.5	15	5,753	s.	30	sw.	1	7	10	13	6.1	.0	.0
Cincinnati	627	11	51	29.37	30.04	−.03	69.8	+2.7	92	25	81	44	28	59	34	61	57	75	3.58	+.9	12	4,504	s.	19	s.	3	7	14	9	5.6	.0	.0
Columbus	822	216	230	29.18	30.04	−.03	68.6	+2.1	89	25	78	45	28	59	27	61	57	74	3.36	+.8	11	6,342	s.	29	sw.	11	9	16	5	5.3	.0	.0
Elkins	1,947	59	78	28.08	30.11	+.03	64.6	+1.6	83	26	77	39	3	52	38	58	56	89	3.82	+.7	11	2,978	se.	28	w.	29	7	10	13	6.3	.0	.0
Parkersburg	637	77	84	29.43	30.08	.00	69.6	+2.3	90	24	81	45	28	58	34	62	60	79	3.29	+.5	12	3,642	se.	18	sw.	27	10	13	7	4.9	.0	.0
Pittsburgh	842	353	410	29.17	30.06	−.02	68.4	+2.0	89	25	78	44	28	59	31	61	58	77	3.78	+1.2	11	5,296	se.	30	nw.	27	8	16	6	5.0	.0	.0

TABLE 1.—*Climatological data for Weather Bureau stations, September 1934*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air											Precipitation			Wind										
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01, or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F	°F	°F		°F	°F		°F	°F	°F	°F	%	In.	In.		Miles								0-10	In.	In.
Lower Lake region							66.3	+3.4										78	3.43	+0.5										6.2		
Buffalo	768	243	280	29.22	30.04	-0.02	65.8	+3.4	87	24	72	45	30	59	24	60	57	79	3.57	+.6	13	8,582	s.	47	sw.	27	8	9	13	6.2	0.0	0.0
Canton	448	10	61	29.58	30.05	-----	63.5	+4.2	87	3	72	39	30	55	30	-----	-----	-----	3.11	-.2	13	5,248	sw.	29	w.	27	4	11	15	7.0	.0	.0
Ithaca	836	77	100	29.18	30.08	-----	65.0	+3.4	86	25	75	39	28	56	33	59	57	82	4.96	+1.9	12	6,503	se.	22	s.	12	4	12	14	6.8	.0	.0
Oswego	335	71	85	29.70	30.06	.00	65.3	+4.1	87	4	73	45	28	58	29	59	56	79	2.98	+.3	10	6,711	se.	26	w.	27	6	6	18	6.9	.0	.0
Rochester	523	86	102	29.50	30.06	.00	66.9	+4.5	88	4	75	46	28	59	28	60	56	75	4.56	+2.1	13	5,138	s.	22	sw.	27	9	5	16	6.3	.0	.0
Syracuse	596	65	79	29.44	30.08	+.01	66.6	+5.0	88	26	75	45	30	58	32	-----	-----	-----	4.71	+2.0	11	4,792	s.	28	sw.	27	4	12	14	7.0	.0	.0
Erie	714	130	166	29.28	30.04	-.02	67.6	+4.0	87	15	76	47	28	60	27	61	58	79	2.93	-.5	12	8,662	s.	30	s.	1	10	10	10	5.4	.0	.0
Cleveland	762	267	337	29.22	30.04	-.02	67.1	+3.2	85	2	74	47	28	60	25	60	57	76	2.12	-1.2	13	8,092	se.	35	n.	7	9	11	10	5.6	.0	.0
Sandusky	629	5	67	29.36	30.03	-.03	68.0	+2.7	90	26	77	42	28	59	31	-----	-----	-----	2.57	-.4	12	5,545	s.	21	nw.	27	4	16	10	6.4	.0	.0
Toledo	628	79	87	29.36	30.03	-.03	67.1	+2.7	86	21	76	45	28	59	28	60	57	77	3.16	+.4	13	5,533	sw.	24	sw.	26	7	16	7	4.9	.0	.0
Fort Wayne	857	69	84	29.10	30.02	-----	65.8	+.3	85	13	74	43	28	57	27	59	56	77	3.56	+.5	13	5,420	s.	30	sw.	15	7	11	12	6.1	.0	.0
Detroit	626	5	78	29.34	30.02	-.04	66.4	+2.9	87	26	76	43	30	57	28	60	57	80	2.89	.0	14	6,025	se.	29	sw.	4	7	13	10	6.1	.0	.0
Upper Lake region							58.8	-0.8										85	3.85	+0.5										7.1		
Alpena	609	13	89	29.35	30.01	-.02	58.2	+.6	83	25	65	38	30	51	30	55	53	89	4.12	+1.1	14	6,937	se.	32	sw.	2	5	10	15	7.1	.0	.0
Escanaba	612	54	60	29.33	29.99	-.02	54.5	-2.6	70	25	61	32	30	48	25	52	50	87	2.93	-.4	17	6,717	s.	27	n.	21	4	10	16	7.2	.0	.0
Grand Rapids	707	70	244	29.23	30.00	-.05	64.1	+1.4	86	25	73	44	30	56	33	58	56	81	5.76	+2.2	16	6,976	s.	40	sw.	15	6	7	17	6.9	.0	.0
Lansing	878	6	88	29.07	30.01	-----	63.0	+1.6	84	26	72	39	17	54	28	58	57	89	2.21	-.7	16	5,549	s.	22	w.	26	6	9	15	6.6	.0	.0
Ludington	637	5	54	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Marquette	734	77	111	29.18	29.99	-.01	54.0	-3.5	79	14	61	36	29	47	26	50	49	86	6.59	+3.3	18	6,100	s.	27	nw.	15	2	10	18	7.8	.0	.0
Sault Sainte Marie	614	11	52	29.31	30.00	-.02	56.3	+.8	81	25	64	34	30	48	33	52	50	85	3.54	-.6	17	4,836	se.	21	sw.	26	4	9	17	7.3	.0	.0
Chicago	673	7	131	29.28	30.00	-.04	64.2	-1.0	88	20	71	43	27	57	34	59	57	81	4.03	+.9	15	6,693	s.	22	sw.	15	5	9	16	7.0	.0	.0
Green Bay	617	109	141	29.32	29.98	-.04	59.1	-1.3	84	25	68	37	30	50	29	54	52	82	1.91	-1.6	9	6,962	s.	28	n.	21	6	5	19	7.3	.0	.0
Milwaukee	681	97	221	29.26	29.99	-.04	61.3	-1.2	85	25	68	42	27	54	32	56	54	81	4.33	+1.0	10	8,276	s.	30	n.	20	7	7	16	6.7	.0	.0
Duluth	1,133	5	47	28.74	29.97	-.01	52.8	-2.3	70	7	61	31	27	45	32	49	47	87	3.10	-.2	15	7,197	ne.	31	sw.	27	5	6	19	7.1	.0	.0
North Dakota							52.3	-4.9										68	0.85	-0.7										5.8		
Moorhead, Minn.	940	50	58	28.94	29.96	.00	53.5	-4.7	89	13	65	26	21	42	39	47	42	72	.93	-1.3	11	6,568	s.	21	n.	13	6	12	12	6.3	T	.0
Bismarck	1,674	8	57	28.17	29.95	+.01	52.6	-5.5	89	7	65	25	15	41	41	46	39	67	.54	-.7	8	6,792	nw.	30	se.	8	8	10	12	6.1	2.5	.0
Devils Lake	1,478	11	44	28.38	29.96	+.02	51.0	-4.9	85	13	62	24	26	40	40	44	38	69	.73	-.9	8	6,945	nw.	29	nw.	13	7	9	14	6.2	1.5	.0
Grand Forks	833	12	67	-----	-----	-----	52.6	-----	88	13	64	24	21	41	43	46	-----	-----	.86	-----	7	-----	nw.	27	nw.	12	5	9	16	-----	T	.0
Williston	1,878	41	48	27.98	29.96	+.03	52.2	-4.4	92	7	63	24	15	41	44	44	37	66	1.19	+.1	12	6,208	n.	25	ne.	13	14	8	8	4.8	2.1	.0
Upper Mississippi Valley							62.5	-2.7										81	6.36	+2.7										6.2		
Minneapolis	918	102	208	28.98	29.96	-----	57.2	-4.2	86	13	66	33	21	48	33	52	48	74	4.86	+1.7	17	7,574	nw.	32	nw.	13	8	8	14	6.3	.0	.0
La Crosse	714	11	48	29.20	29.96	-.05	59.4	-2.8	84	1	69	35	27	50	31	55	53	87	9.04	+5.0	14	3,364	s.	14	sw.	27	5	9	16	7.0	.0	.0
Madison	974	70	78	28.94	29.97	-.06	60.6	-1.8	84	25	69	37	27	52	31	56	53	84	4.25	+.5	14	5,738	s.	21	n.	21	7	6	17	6.8	.0	.0
Charles City	1,015	10	51	28.90	29.98	-.02	58.0	-3.0	82	24	68	33	27	48	33	53	50	82	7.47	+3.8	14	4,880	se.	20	se.	24	11	5	14	5.7	.0	.0
Davenport	606	66	161	29.34	29.99	-.04	63.4	-2.2	86	25	72	38	27	54	32	58	55	81	7.91	+4.3	16	6,153	sw.	24	nw.	20	11	2	17	6.3	.0	.0
Des Moines	861	5	99	29.07	29.97	-.05	61.4	-4.2	88	11	72	35	27	51	33	55	52	77	6.20	+2.5	12	6,590	se.	25	nw.	15	10	5	15	6.1	.0	.0
Dubuque	700	60	79	29.23	29.98	-.05	61.9	-2.1	86	25	71	38	27	53	31	56	53	79	6.54	+2.5	14	4,122	s.	18	sw.	1	8	6	16	6.4	.0	.0
Keokuk	614	64	78	29.33	30.00	-.03	64.4	-3.1	87	11	74	38	27	55	29	58	55	77	6.40	+2.6	15	5,154	s.	19	s.	25	11	6	13	5.7	.0	.0
Cairo	358	87	93	29.64	30.01	-.04	68.6	-2.9	89	20	77	52	27	60	28	62	60	82	6.02	+3.1	13	5,438	s.	25	nw.	13	7	8	15	6.4	.0	.0
Peoria	609	11	45	29.35	30.02	-.02	63.8	-.5	88	20	73	39	27	54	36	58	57	87	6.57	+2.5	13	4,116	s.	14	sw.	1	12	7	11	5.3	.0	.0
Springfield, Ill.	636	5	191	29.32	30.00	-.05	65.2	-2.4	91	20	74	43	27	56	38	60	57	82	5.24	+1.6	11	7,258	s.	34	w.	26	7	10	13	6.2	.0	.0
St. Louis	568	265	303	29.40	30.00	-.04	66.6	-3.5	91	20	75	45	27	58	37	60	57	79	5.86	+2.4	15	7,983	s.	36	sw.	12	9	8	13	6.0	.0	.0
Missouri Valley							62.6	-3.9										71	4.90	+1.5										4.8		
Columbia, Mo.	784	6	84	29.16	29.98	-.05	65.2	-3.0	87	11	75	38	27	56	28	-----	-----	-----	8.31	+4.0	16	5,386	se.	28	w.	11	10	9	11	5.3	.0	.0
Kansas City	750	32	45	29.17	29.97	-.05	65.8	-3.1	92	11	77	37	27	55	35	58	55	76	6.44	+1.9	14	6,613	s.	27	nw.	20	10	11	9	5.2	.0	.0
St. Joseph	967	11	49	28.94	29.97	-----	63.5	-----	91	11	74	38	27	53	31	57	53	76	7.05	+3.2	14	5,821	se.	28	nw.	2	11	7	12	5.2	.0	.0
Springfield, Mo.	1,324	98	104	28.61	30.00	-.03	65.8	-3.1	87	11	76	41	27	56	31	59	55	77	6.50	+3.0	13	6,778	se.	27	w.	20	12	9	9	4.7	.0	.0
Iola	984	11	50	28.95	29.98	-.03	67.3	-2.5	93	1	80	36	27	55	39	-----	-----	-----	7.62	+2.7	12	-----	n.	-----	-----	-----	13	7	10	-----	.0	.0
Topeka	987	65	87	-----	-----	-----	65.0	-3.7	91	11	76	40	27	54	36	-----	-----	-----	4.94	+1.1	12	6,701	s.	29	s.	24	13	10	7	4.4	.0	.0
Lincoln	1,189	11	81	28.70	29.95	-.04	62.4	-4.0	92	19	74	36	26	51	35	54	49	70	4.47	+1.5	9	7,457	s.	32	sw.	10	12	9	9	4.4	.0	.0
Omaha	1,105	170	200	28.80	29.97	-.03	62.0	-4.8	89	19	73	36	26	51	33	54	49	70	2.32	-.9	10	8,569	s.	31	n.	20	14	6	10	4.7	.0	.0
Valentine	2,598	47	54	27.28	29.98	+.02	56.4	-6.1	90	13	70	23	26	43	41	47	40	63	1.31	.0	8	7,050	n.	29	sw.	8	12	10	8	5.0	T	.0
Sioux City	1,138	64	106	28.75	29.96	-.02	59.4	-4.0	89	19	70	33	21	48	37	52	48	72	3.43	+.4	9	7,055	se.	25	se.	9	13	6	11	4.9	.0	.0
Huron	1,306	60	74	28.57	29.97	+.01	56.9	-4.4	90	13	69	28	21	45	43	48	42	65	1.52	.0	10	7,309	se.	22	n.	14	14	5	11	4.6	.0	.0
Northern Slope							53.1	-4.3										59	1.32	+0.1										5.2		
Billings	3,140	4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Havre	2,505	11	67	27.36	30.00	+.06	51.4	-5.0	88	6	64	20	25	39	47	43	36	65	1.74	+.4	11	6,259	sw.	25	sw.	27	7	15	8	5.6	8.7	.0
Helena	4,124	85	111	25.82	30.00	+.03	51.8	-4.8	85	6	63	19	24	40	37	42	33	54	.63	-.6	9	6,400	sw.	30	sw.	26	6	10	14	6.5	6.4	.0
Kalispell	2,973	48	56	-----	30.01	+.05	51.2	-2.3	88	6	63	17	25	40	42	-----	-----	61	.71	-.5	7	4,394	w.	23	w.	12	6	8	16	-----	T	.0
Miles City	2,371	48	55	27.47	30.02	+.07	54.7	-6.5	92	7	67	26	25	42	42	44	35	56	1.04	.0	5	4,763	s.	24	n.	13	9	10	11	5.8	3.5	.0
Rapid City	3,259	50	58	26.61	30.01	+.03	55.6	-4.8	94	12	69	19	26	42	41	46	37	56	.38	-.8	5	6,617	n.	28	n.	5	13	8	9	4.8	.4	.0
Cheyenne	6,094	50	71	24.04	29.96	.00	53.4	-3.6	84	1	68	21	25	39	43	41	31	54	.72	-.5	5	6,849	w.	29	nw.	29	11	13	6	4.7	1.2	.0
Lander	5,372	60	68	24.67	29.99	+.03	53.1	-2.6	88	4	68	21	26	38	45	43	33	57	1.67	+.8	7	3,698	sw.	37	sw.	11	11	12	7	4.6	4.3	.0
Sheridan	3,790	10	47	26.11	30.01	-----	51.8	-----	92	7	67	24	26	37	50	42	33	62	1.90	+.6	10	3,589	nw.	21	nw.	13	12	7	11	5.1	9.0	.0
Yellowstone Park	6,241	11	48	-----	30.03	+.06	47.2	-6.2	81	6	60	15	24	34	43	-----	-----	55	.95	-.3	8	5,956	sw.	28	sw.	12	10	7	13	-----	8.5	.0
North Platte	2,821	11	51	27.05	29.96	-.01	59.6	-2.5	91	13	74	26	26	46	43	50	44	67	3.50	+2.2	6	6,125	n.	25	n.	17	15	7	8	4.2	T	.0
Middle Slope							65.2	-2.8										60	2.57	+0.5										4.2		
Denver	5,292	106	113	24.75	29.94	-0.02	60.7	-2.2	89	4	75	30	25	46	42	46	33	46	.50	-0.5	6	5,607	s.	35	n.	14	12	12	6	4.1	T	0.0
Pueblo	4,685	80	86	25.30	29.93	-.03	64.0	-.6	91	19	80	33	27	48	49	48	35	44	.34	-.4	5	5,105	e.	27	ne.	14	12	15	3	4.0	.0	.0
Concordia	1,392	50	58	28.52	29.99		64.6	-3.7	94	19	77	35	26	52	38	55	50	66	1.82	-.8	11	6,604	s.	25	n.	2	13	10	7	4.4	.0	.0
Dodge City	2,509	10	86	27.40	29.97	-.01	65.6	-3.8	98	12	79	33	26	52	36	55	48	62	2.05	+.2	7	9,962	s.	35	ne.	20	16	11	3	3.1	.0	.0
Wichita	1,358	85	93	28.54	29.96	-.04	66.4	-4.2	93	12	78	40	26	55	38	58	52	68	4.25	+1.2	9	8,022	s.	32	nw.	2	13	9	8	4.6	.0	.0
Oklahoma City	1,214	10	47	28.70	29.96	-.03	70.2	-2.6	91	20	81	43	27	60	40	61	58	72	6.45	+3.4	9	7,214	s.	26	nw.	2	10	15	5	4.7	.0	.0

TABLE 1.—*Climatological data for Weather Bureau stations, September 1934*—Continued

District and station	Elevation of instruments			Pressure			Temperature of the air												Precipitation			Wind										
	Barometer above sea level	Thermometer above ground	Anemometer above ground	Station, reduced to mean of 24 hours	Sea level, reduced to mean of 24 hours	Departure from normal	Mean max. + mean min. ÷ 2	Departure from normal	Maximum	Date	Mean maximum	Minimum	Date	Mean minimum	Greatest daily range	Mean wet thermometer	Mean temperature of the dew-point	Mean relative humidity	Total	Departure from normal	Days with 0.01, or more	Total movement	Prevailing direction	Maximum velocity: Miles per hour	Maximum velocity: Direction	Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F	°F	°F		°F	°F		°F	°F	°F	°F	%	In.	In.		Miles								0-10	In.	In.
Southern Slope							74.8	+1.2										56	1.39	-1.1										3.6		
Abilene	1,738	10	52	28.16	29.92	-0.04	77.3	+2.0	99	2	90	53	16	65	37	63	55	54	.86	-1.8	3	8,002	s.	26	s.	23	17	11	2	3.5	0.0	0.0
Amarillo	3,676	10	49	26.28	29.94	-.02	70.1	+.8	96	2	85	40	21	56	43	56	47	54	.96	-1.3	5	7,137	s.	28	ne.	2	17	11	2	3.6	.0	.0
Big Spring	2,537	5	62	27.36	29.93	----	75.0	----	98	20	87	51	16	63	37	62	56	59	.58	----	3	----	s.	----	----	----	18	10	2	3.2	.0	.0
Del Rio	944	64	71	28.91	29.87	-.07	79.8	+.6	94	2	89	63	4	71	27	69	65	65	3.75	+.8	4	7,379	se.	41	n.	14	8	17	5	5.1	.0	.0
Roswell	3,566	75	85	26.36	29.90	-.02	71.8	+1.5	96	5	86	46	26	58	41	56	46	47	T	-2.1	0	5,845	s.	35	ne.	2	21	6	3	2.6	.0	.0
Southern Plateau							72.8	+2.0										46	0.54	-0.2										2.1		
El Paso	3,778	152	175	26.16	29.84	-.04	77.8	+3.9	98	5	90	58	29	66	35	58	43	35	.17	-1.1	3	6,872	e.	32	ne.	12	25	4	1	1.4	.0	.0
Albuquerque	4,972	5	39	25.07	29.86	----	67.2	----	93	5	81	44	29	53	39	54	46	56	1.08	+.3	6	5,505	n.	40	nw.	6	17	8	5	3.2	.0	.0
Santa Fe	7,013	38	53	23.33	29.90	-.03	60.4	-.5	82	5	72	37	26	49	32	48	38	51	1.34	-.1	6	4,243	e.	23	e.	11	14	10	6	4.0	.0	.0
Flagstaff	6,907	10	59	23.41	29.87	-.02	57.0	+1.5	83	4	74	22	26	40	49	45	----	56	.26	----	5	----	sw.	27	sw.	23	14	13	3	----	.0	.0
Phoenix	1,108	10	107	28.66	29.78	-.03	84.8	+2.1	108	3	99	52	28	71	43	63	48	35	.66	-.1	2	4,110	e.	21	sw.	23	24	5	1	1.5	.0	.0
Yuma	141	9	54	29.62	29.76	-.02	85.6	+1.9	110	15	102	53	26	69	49	66	54	41	T	-.4	0	3,673	w.	20	nw.	23	29	0	1	.5	.0	.0
Independence	3,957	5	26	25.94	29.91	+.05	71.2	+3.2	99	3	88	39	27	55	40	51	----	----	.00	-.1	0	----	n.	----	----	----	28	1	1	----	.0	.0
Middle Plateau							62.8	+0.9										35	0.44	-0.2										1.9		
Reno	4,527	61	76	25.48	29.92	-.03	63.4	+3.7	95	3	80	29	26	47	41	47	33	39	.13	-.1	1	4,442	w.	27	w.	23	26	2	2	1.4	T	.0
Tonopah	6,090	12	20				65.4	----	90	4	77	29	25	54	33	46	28	28	.21	----	2	----	nw.	----	----	----	----	----	----	----	----	----
Winnemucca	4,344	18	56	25.62	29.96	+.03	59.8	+.6	97	4	80	17	26	40	51	43	26	34	.25	-.2	2	5,139	ne.	23	sw.	23	25	3	2	1.4	T	.0
Modena	5,473	10	46	24.62	29.88	-.04	61.2	+1.2	91	4	79	29	27	44	44	45	28	35	.72	-.1	3	7,665	sw.	48	sw.	23	23	6	1	1.9	.4	.0
Salt Lake City	4,360	86	210	25.62	29.93	-.02	63.6	-.8	90	1	76	34	27	51	35	47	32	36	.40	-.6	5	5,481	nw.	31	se.	7	20	6	4	2.8	.0	.0
Grand Junction	4,602	60	68	25.36	29.90	-.05	65.9	-.3	90	5	80	35	28	51	38	49	34	38	.72	-.2	4	4,911	se.	27	sw.	23	23	5	2	2.2	.0	.0
Northern Plateau							60.0	-0.4										44	0.45	-0.3										4.6		
Baker	3,471	48	53	26.46	30.03	+.04	55.6	-.4	90	5	71	26	26	40	45	44	32	46	.29	-.4	2	4,827	n.	20	n.	19	14	9	7	4.5	1.7	.0
Boise	2,739	79	87	27.15	29.98	+.01	61.4	-.5	93	6	76	28	26	47	37	47	33	38	.04	-.5	3	3,764	nw.	17	nw.	7	16	11	3	3.6	T	.0
Pocatello	4,477	60	68	25.47	29.94	-.02	59.6	-.6	88	6	73	31	27	46	43	44	28	36	.41	-.4	2	6,732	se.	27	sw.	22	16	7	7	3.9	T	.0
Spokane	1,929	101	110	27.96	30.00	+.02	57.6	-1.6	92	4	70	28	25	46	39	46	35	50	.98	+.1	7	4,616	s.	26	ne.	23	10	7	13	5.6	.0	.0
Walla Walla	991	57	65	28.92	29.98	-.02	64.0	+.2	98	4	75	36	25	53	35	51	38	44	.60	-.4	6	4,036	s.	17	w.	12	11	12	7	4.7	.0	.0
Yakima	1,076	58	67	28.86	30.00	----	61.7	+.6	96	4	75	34	25	49	38	50	39	50	.37	-.1	5	4,253	nw.	25	n.	23	11	11	8	5.1	.0	.0
North Pacific Coast Region							59.4	+0.9										69	1.65	-0.6										5.0		
North Head	211	11	56	29.83	30.06	+.03	57.0	+.5	93	2	61	46	23	53	37	54	52	86	2.24	-.8	14	7,675	n.	37	s.	12	5	12	13	6.5	.0	.0
Seattle	125	90	321	29.90	30.03	+.02	59.5	+1.4	90	2	66	42	25	53	30	53	48	68	2.22	+.4	8	5,539	n.	32	sw.	12	6	10	14	6.4	.0	.0
Tatoosh Island	86	10	54	29.96	30.05	+.04	54.1	+1.1	73	3	58	43	25	50	18	52	50	90	3.23	-1.4	15	7,501	s.	42	sw.	12	5	6	19	6.8	.0	.0
Medford	1,329	29	58	28.56	29.95	----	65.3	----	104	2	84	34	26	46	49	51	39	47	.31	-.2	3	4,107	nw.	26	nw.	22	25	4	1	1.8	.0	.0
Portland, Oreg.	153	68	106	29.87	30.03	.00	62.8	+1.1	95	2	72	39	25	53	33	55	50	66	1.32	-.7	7	4,220	nw.	17	sw.	22	7	14	9	5.6	.0	.0
Roseburg	510	45	76	29.46	30.01	-.01	63.4	+.5	104	2	78	35	26	48	48	53	44	56	.57	-.7	2	3,411	n.	17	n.	21	17	9	4	3.0	.0	.0
Middle Pacific Coast Region							63.6	+1.6										59	0.20	-0.4										2.4		
Eureka	62	73	89	29.93	30.00	-.01	54.7	-1.2	65	5	60	41	25	49	18	52	50	89	.47	-.5	3	4,426	n.	27	n.	13	13	9	8	4.3	.0	.0
Redding	722	20	34	----	----	----	77.6	----	105	2	91	44	24	64	36	56	36	27	.05	----	2	----	nw.	----	----	----	24	4	2	1.5	.0	.0
Sacramento	66	92	115	29.78	29.85	-.04	72.5	+3.2	102	15	89	44	25	56	46	58	46	46	.01	-.4	1	5,580	s.	22	sw.	21	25	5	0	1.0	.0	.0
San Francisco	155	208	243	29.74	29.90	-.04	63.6	+2.7	92	14	72	52	1	55	30	55	51	74	.13	-.3	1	4,765	sw.	24	sw.	9	16	10	4	3.0	.0	.0
South Pacific Coast Region							73.0	+3.2										56	0.11	0.0										2.6		
Fresno	327	97	105	29.51	29.85	-.02	76.6	+3.2	103	3	92	45	25	61	39	57	40	33	.01	-.2	1	4,313	nw.	17	nw.	24	25	4	1	1.2	.0	.0
Los Angeles	338	159	191	29.53	29.88	.00	72.7	+3.7	98	18	82	54	25	63	31	60	54	60	.13	.0	1	3,839	sw.	17	sw.	25	18	8	4	2.9	.0	.0
San Diego	87	62	70	29.78	29.88	-.01	69.7	+2.6	89	17	76	55	26	64	23	63	59	74	.18	+.1	2	4,664	nw.	19	nw.	15	19	9	2	3.6	.0	.0
West Indies																																
San Juan, P. R.	82	9	54	29.88	29.95	----	80.2	-.3	91	1	85	72	28	75	16	----	----	----	11.56	+5.6	20	6,673	e.	32	e.	27	2	18	10	6.3	.0	.0
Panama Canal																																
Balboa Heights	118	6	97	----	[1] 29.82	.00	80.4	+.6	91	2	86	71	15	74	16	----	----	[1] 88	16.38	+8.2	20	3,641	nw.	22	nw.	3	0	14	16	7.6	.0	.0
Cristobal	36	6	97	----	[1] 29.83	.00	81.0	+.6	90	24	86	70	5	76	18	76	76	[1] 86	21.30	+9.0	26	4,039	w.	32	nw.	12	0	3	27	9.0	.0	.0
Alaska																																
Fairbanks	454	11	87	[2] 29.44	[2] 29.96	----	45.9	----	71	23	57	24	30	35	35	40	31	58	.55	----	5	5,158	ne.	30	n.	16	12	8	10	5.2	.0	.0
Juneau	80	96	116	[2] 29.94	[2] 30.03	----	50.9	----	70	9	57	37	23	45	24	46	39	69	5.15	----	15	4,986	s.	32	ne.	11	5	9	16	6.8	.0	.0
Hawaiian Islands																																
Honolulu	38	86	100	[2] 29.94	[2] 29.98	----	79.0	+.8	87	14	84	71	11	74	12	72	69	72	2.82	+1.5	21	6,161	e.	27	e.	26	10	14	6	4.9	.0	.0

[1] Observations taken bihourly.
[2] Pressure not reduced to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, September 1934*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max. + mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*In.*	*In.*	*In.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	*In.*	*In.*	*In.*
Cape Race, Newfoundland	99				55.0		61.8	48.2	71	33	1.27		0.0
Sydney, Cape Breton Island	48	30.11	30.16	+0.15	63.7	+7.2	73.5	54.0	86	39	1.34	−1.94	.0
Halifax, Nova Scotia	88	29.93	30.03	−.01	64.0	+6.4	70.3	57.8	78	47	5.18	+1.47	.0
Yarmouth, Nova Scotia	65	30.04	30.11	+.06	62.6	+6.5	71.1	54.0	79	36	2.99	−.62	.0
Charlottetown, Prince Edward Island	38	30.14	30.18	+.17	62.8	+5.5	69.2	56.4	79	47	1.49	−1.91	.0
Chatham, New Brunswick	28	30.02	30.05	+.05	60.4	+5.0	70.4	50.3	83	37	2.15	−.56	.0
Father Point, Quebec	20	30.04	30.06	+.08	54.2	+3.8	62.5	45.8	82	36	1.50	−1.63	.0
Quebec, Quebec	296	29.79	30.11	+.10	60.6	+5.5	66.8	54.4	78	40	3.48	−.19	.0
Doucet, Quebec	1,236				53.7		63.9	43.5	81	26	5.45		1.6
Montreal, Quebec	187												
Ottawa, Ontario	236	29.80	30.06	+.02	62.8	+5.4	71.2	54.5	86	41	4.17	+1.48	.0
Kingston, Ontario	285	29.75	30.06	+.02	64.0	+4.0	69.9	58.1	79	48	4.93	+2.13	.0
Toronto, Ontario	379	29.63	30.03	+.03	62.9	+3.9	69.6	56.2	78	44	4.24	+.99	.0
Cochrane, Ontario	930				53.3		61.0	45.6	78	30	5.65		.5
White River, Ontario	1,244	28.67	29.99	+.01	49.5	−.8	59.7	39.3	76	18	5.17	+2.40	.0
London, Ontario	808				62.7		70.8	54.6	82	38	4.48		.0
Southampton, Ontario	656	29.30	30.01	−.04	61.4	+3.9	69.4	53.4	84	37	4.76	+1.82	.0
Parry Sound, Ontario	688	29.33	30.01	−.02	61.1	+5.1	67.9	54.3	82	41	3.81	+.14	.0
Port Arthur, Ontario	644	29.27	29.98	.00	50.6	−1.6	56.6	44.6	66	30	4.38	+.90	.0
Winnipeg, Manitoba	760	29.12	29.95	+.01	50.5	−2.0	58.9	42.0	83	26	4.34	+2.31	4.3
Minnedosa, Manitoba	1,690	28.13	29.95	+.01	47.3	−3.2	57.1	37.6	86	25	2.73	+1.37	1.8
Le Pas, Manitoba	860		29.97		46.0		55.3	36.7	85	22	3.46		1.0
Qu'Appelle, Saskatchewan	2,115	27.68	29.93	+.01	46.4	−4.7	57.2	35.5	88	12	1.62	+.29	10.6
Moose Jaw, Saskatchewan	1,759				47.8		58.6	36.9	85	12	1.60		8.6
Swift Current, Saskatchewan	2,392	27.40	29.93	+.01	47.4	−5.7	57.7	37.1	88	15	1.89	+.67	2.9
Medicine Hat, Alberta	2,365	27.44	29.93	+.01	48.9	−6.1	59.1	38.7	88	9	2.22	+1.04	9.5
Calgary, Alberta	3,540	26.30	29.99	+.07	45.7	−4.1	56.2	35.2	82	10	2.23	+.87	12.2
Banff, Alberta	4,521	25.43	30.02	+.09	44.0	−1.8	55.1	32.8	84	12	1.40	−.27	6.0
Prince Albert, Saskatchewan	1,450	28.42	30.00	+.10	45.6	−2.8	55.4	35.8	88	20	1.04	−.24	.0
Battleford, Saskatchewan	1,592	28.24	29.99	+.09	45.6	−6.2	56.1	35.1	88	18	.95	−.30	1.3
Edmonton, Alberta	2,150	27.70	30.00	+.10	44.2	−5.1	52.8	35.5	88	15	2.39	+1.06	9.4
Kamloops, British Columbia	1,262	28.74	30.02	+.05	57.0	−.4	67.3	46.8	91	34	1.16	+.31	.0
Victoria, British Columbia	230	29.79	30.04	+.03	54.2	−.6	63.3	45.0	87	42	1.26	−.90	.0
Barkerville, British Columbia	4,180												
Estevan Point, British Columbia	20				54.8		60.4	49.2	72	30	5.99		.0
Prince Rupert, British Columbia	170				52.5		59.4	45.6	74	34	9.86		.0
Hamilton, Bermuda	151	29.98	30.14	+.07	80.4	+3.0	86.0	74.8	89	70	1.85	−4.66	.0
LATE REPORTS FOR AUGUST 1934													
Southampton, Ontario	656	29.31	30.02	+.03	61.6	−2.2	71.8	51.5	90	34	2.39	+.14	.0

SEVERE LOCAL STORMS, SEPTEMBER 1934

[Compiled by Mary O. Souder]

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A revised list of tornadoes will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Pratt County, Kans	2	3:30-4 p. m.	120	0		Tornado	Few telephone poles blown down; only slight damage reported; path 15 miles long.	Official, U. S. Weather Bureau.
Rifle, near, Colo	3					Heavy rain	A landslide caused by local storms partially dammed the Colorado River closing both the railway and the highway, temporarily interfering with traffic.	Do.
New Haven, Conn., and vicinity.	8	P. m.				Wind and rain	Electric wires and some transportation lines impaired; in Milford trolley cars were inundated, delaying schedule.	Do.
Brooklyn, N. Y., and vicinity	8	9 p. m.		1		Heavy wind and rain.	Traffic almost impossible; service on the Long Island R. R. between Flatbush and east New York held up for several hours; cellars flooded; derrick broke loose; boy drowned while sailing.	Do.
Atlantic City, N. J., vicinity of	8	P. m.		3		Wind and rain	3 men on fishing trip drowned when their 35-foot power boat capsized 2½ miles off shore.	Do.
Hatteras, N. C., and nearby coastal areas.	8					do	Maximum wind velocity of 64 miles at 6 a. m., and 7.72 inches of precipitation for the 24 hours ending 8 a. m.; no property damage or loss of life reported.	Do.
Arnett, Okla., 4 miles south	9	3 p. m.	[1] 2		$25,000	Hail	Crop loss $25,000; hailstones as large as hen eggs destroyed practically all crops in the main path which was 12 miles long.	Do.
Pampa, Tex., and vicinity	9	do	[1] 18		12,000	do	$2,000 loss in fruit and $10,000 to other crops; path 20 miles long.	Do.
Bristol, Tex	9	5:30 p. m.	200	0		Tornado	Buildings damaged	Do.
Erick, Okla., vicinity of	9	6 p.m.	[1] 2		20,000	Hail	Cotton and feed crops destroyed	Do.
Buffalo, N. Y., and vicinity	12	1:45-7:15 p. m.		1	5,000	Electrical and rain.	A number of transformers of the General Electric Co. struck by lightning; sewers and viaducts flooded, delaying traffic; several houses struck by lightning; at Albion a man who sought refuge in a shack killed by lightning.	Do.

[1] Miles instead of yards.

SEVERE LOCAL STORMS, SEPTEMBER 1934—Continued

Place	Date	Time	Width of path (yards)	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Chicago, Ill., and vicinity	12	2:07-3:50 p. m.				Thunderstorm, excessive rain.	Streets and basements flooded; traffic delayed; some damage from lightning.	Official, U. S. Weather Bureau.
Clyde, Okla	12	4 p.m.	880	0	600	Tornado and hail.	Telephone and telegraph wires blown down; church twisted from its foundation; other property damaged.	Do.
Paducah, Tex	13	5:35 p. m.	[1] 5		5,000	Hail	Crop loss $5,000; roofs damaged; poultry, birds and rabbits killed; path 15 miles long.	Do.
Fredericksburg, Va., and vicinity.	13-14			1	40,000	Heavy rain and flood.	Fireman killed and engineer and brakeman injured when a train on the Virginia Central R. R. went through a trestle weakened by a washout carrying away some of the bridge supports; property damaged; severe loss in lowland crops.	Do.
Avondale, Colo	14	5 p. m.	[1] 7			Heavy rain and hail.	Creeks overflowed; bridges and several hundred feet of railway tracks washed out; loss of several thousand dollars to poultry, crops, and property.	Do.
Jerseyville, Ill	14					Wind	Telephone and electric service disrupted; trees uprooted and several buildings damaged.	Do.
Harrisburg and Mecklenburg Counties, Va.	14		[1] 40		23,000	Heavy rain	Roads heavily damaged; 15 bridges washed out	Do.
Norfolk and Princess Anne Counties and Richmond, Va.	16			1		Heavy rain and flood.	11 persons injured; rivers overflowed; 3 bridges washed out; traffic congested; property damaged and loss to crops.	Do.
Southampton, Sussex, Nansemond and Isle of Wight Counties, Va.	16		[1] 50		36,500	Heavy rain	Roads damaged and 13 bridges washed out	Do.
Washington County, Va	16		[1] 40		19,000	do	Secondary roads washed out and undermined	Do.
Amherst and Nelson Counties, Va.	17		[1] 30		22,000	do	Many road slides and many bridges washed away	Do.
Wrightsville Beach, and Harbor Island, N. C.	19	1:30 p. m.				Waterspout	With a black sky for a background and a calm ocean for a base, the tall column of rising water made a striking picture; the phenomenon lasted 15 minutes and appeared to be about a mile off Moores Inlet; grew larger as it approached the shore; the water around the base seemed to be boiling and churning but the remainder of the ocean was glassy calm; after growing to large proportions the waterspout dwindled away as though someone had begun cutting the strands of a string one by one, and finally entirely disappeared.	Do.
Butler and Greenwood Counties, Kans.	20	3:30 p. m.	[1] 15		15,000	Wind, rain, and hail.	Storm had tornadic characteristics; oil rigs blown down; roof of large garage blown off; in Eureka 5 inches of rain fell in 2 hours flooding the city; path 35 miles long.	Do.
M ntana	20-25					Snowfall	An unseasonably early and unprecedented heavy snowfall for some sections, particularly the north-central; shade trees damaged considerably by accumulated wet snow breaking off branches as large as 4 to 5 inches in diameter; traffic interfered with; hundreds of sheep lost from crowding in corrals and drifting over cutbanks; in Helena greatest amount of snowfall ever accumulated on the ground in September occurred on the 22d when 4.8 inches was measured at 10 a. m.; in Havre the greatest depth on ground was 6.5 inches at 6 a. m. of the 24th.	Do.
Alpena, Mich	21	2-4 p. m.				Electrical and rain.	Lightning struck a residence and caused a factory to suspend operations until repairs could be made; no estimate of damage given.	Do.
Rockville and Montezuma, Ind.	21	2:45 p. m.		2		Thunderstorm	Man killed by lightning in Rockville, another in Montezuma.	Do.
Northumberland and Lancaster Counties, Va.	21		[1] 30		29,000	Heavy rainfall	Damage to roads, bridges, and mill dams; roads impassable for several days.	Do.
Loup City and Ashton, Nebr.	23	6 p. m.	[1] 1	0	10,000	Tornado	3 persons injured; property damaged	Do.
Colby, Kans., 7 miles southwest to 2 miles east.	23	6:30 p. m.	440	0	2,725	do	Large barn and a number of smaller buildings damaged; path 9 miles long.	Do.
Greeley to Spalding, Nebr.	23	7:30-8 p.m.	[1] 1	0	5,000	do	Property damaged	Do.
Petersburg to Elgin, Nebr.	23	8 p. m.	1,000	0	30,000	do	Damage to property	Do.
Minnesota, extreme southeastern counties bordering the Mississippi River.	23-26				12,740	Excessive rain and flood.	Lowlands in the Whitewater, Root, and Zumbro River Valleys inundated; 2 highway bridges near Mazeppa washed out; in Winona the Mississippi River rose 2 feet and several streets were flooded; damage to highways, railroad property, and to crops.	Do.
Pepin, Buffalo, Trempealeau and northern La Crosse Counties, Wis.	25-26					Heavy rain	Streams and smaller rivers overflowed, causing much damage to highways and bridges; steel bridge 40 feet long washed 300 feet down stream on Big Waumandee Creek, Buffalo County.	Do.
Watonga, Okla., vicinity of	27	P. m.	[1] 3			Hail	Crops in storm path completely destroyed; property damaged; path 11 miles long.	Do.
Montgomery County, Kans	28	6:40 p. m.			1,200	Wind	Damage to residences, outbuildings, power and telephone lines; path 8 miles long.	Do.
Springfield, Mo., 1½ miles south of.	29	3:45 a. m.	100		500	Tornadic wind	Noise as though 3 large trucks without mufflers going fast down the street; heavy parcel post sheet iron box moved along street about 100 yards; 15 minutes after storm passed the air was filled with twigs, paper composition roofing and other light debris; small metal beauty parlor sign picked up and its original location not determined, as no such shop located anywhere in this vicinity; no increase in the rain which had been falling since the 28th; plate glass windows in 3 stores blown out; ruins of metal garage blown by the wind deposited in a back yard; padlock stripped with its hinges from a garage door and doors swung open without any material damage.	Do.

[1] Miles instead of yards.

Chart I. Departure (°F.) of the Mean Temperature from the Normal, September 1934

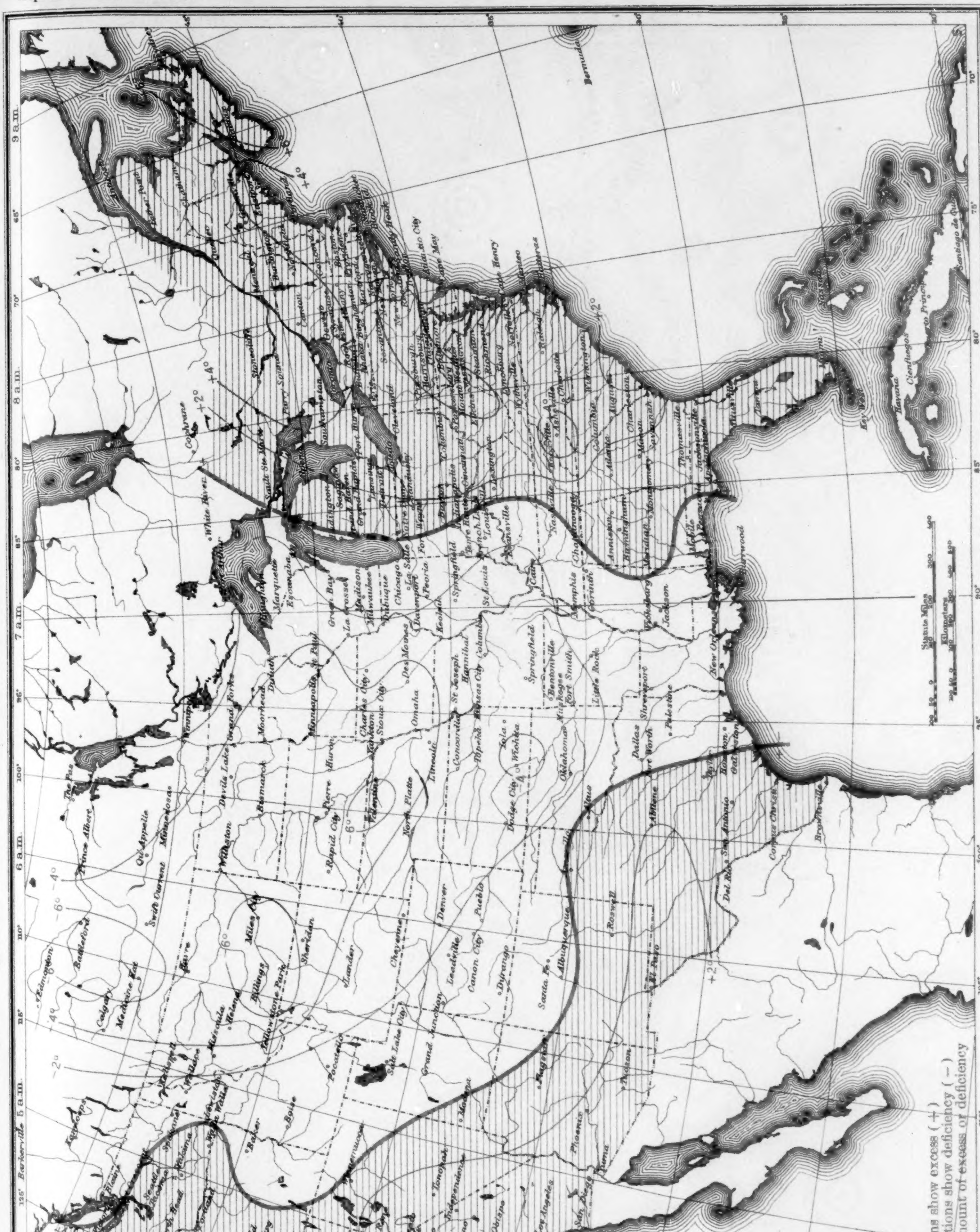
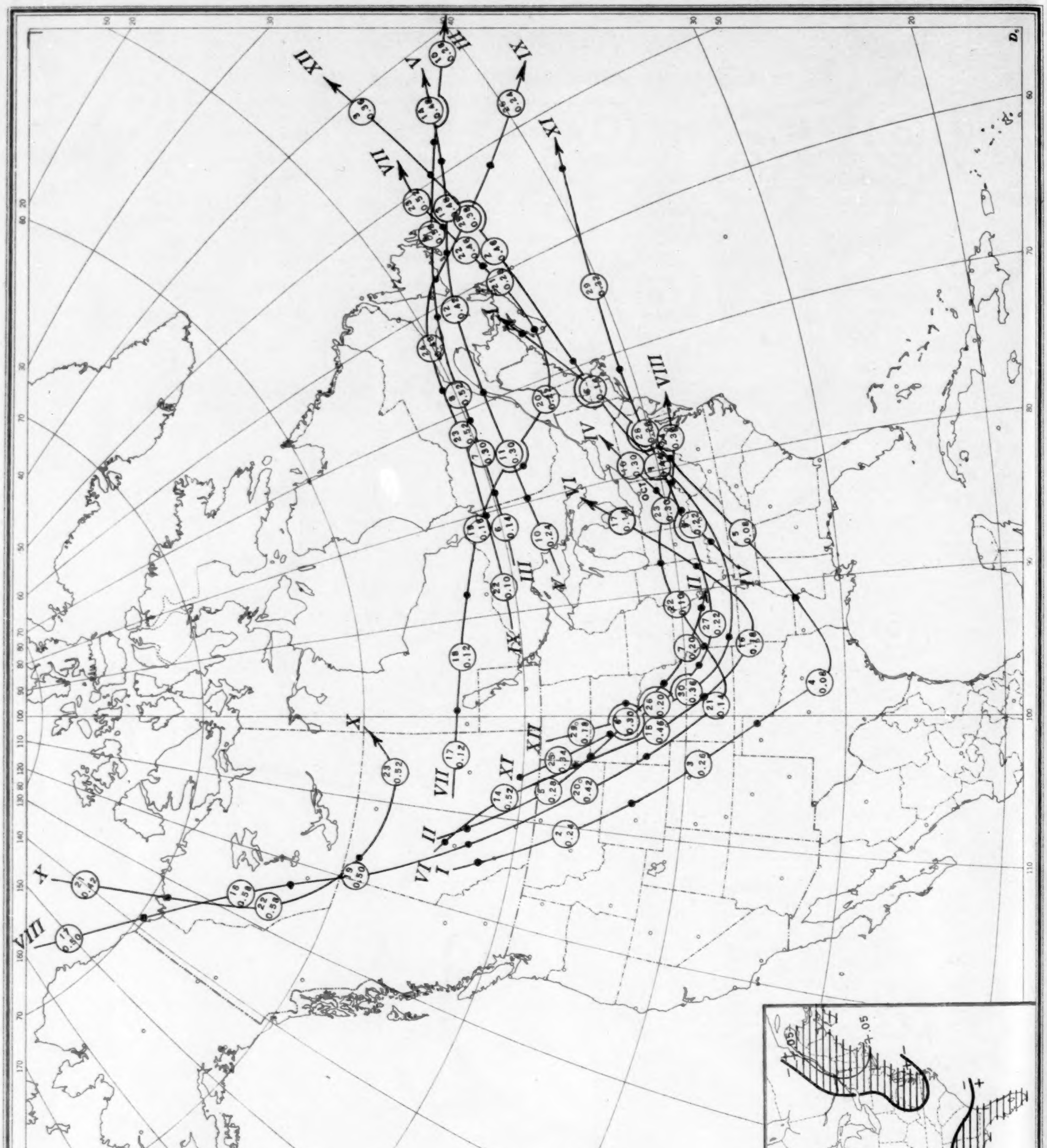


Chart II. Tracks of Centers of Anticyclones, September 1934. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by G. E. Dunn)

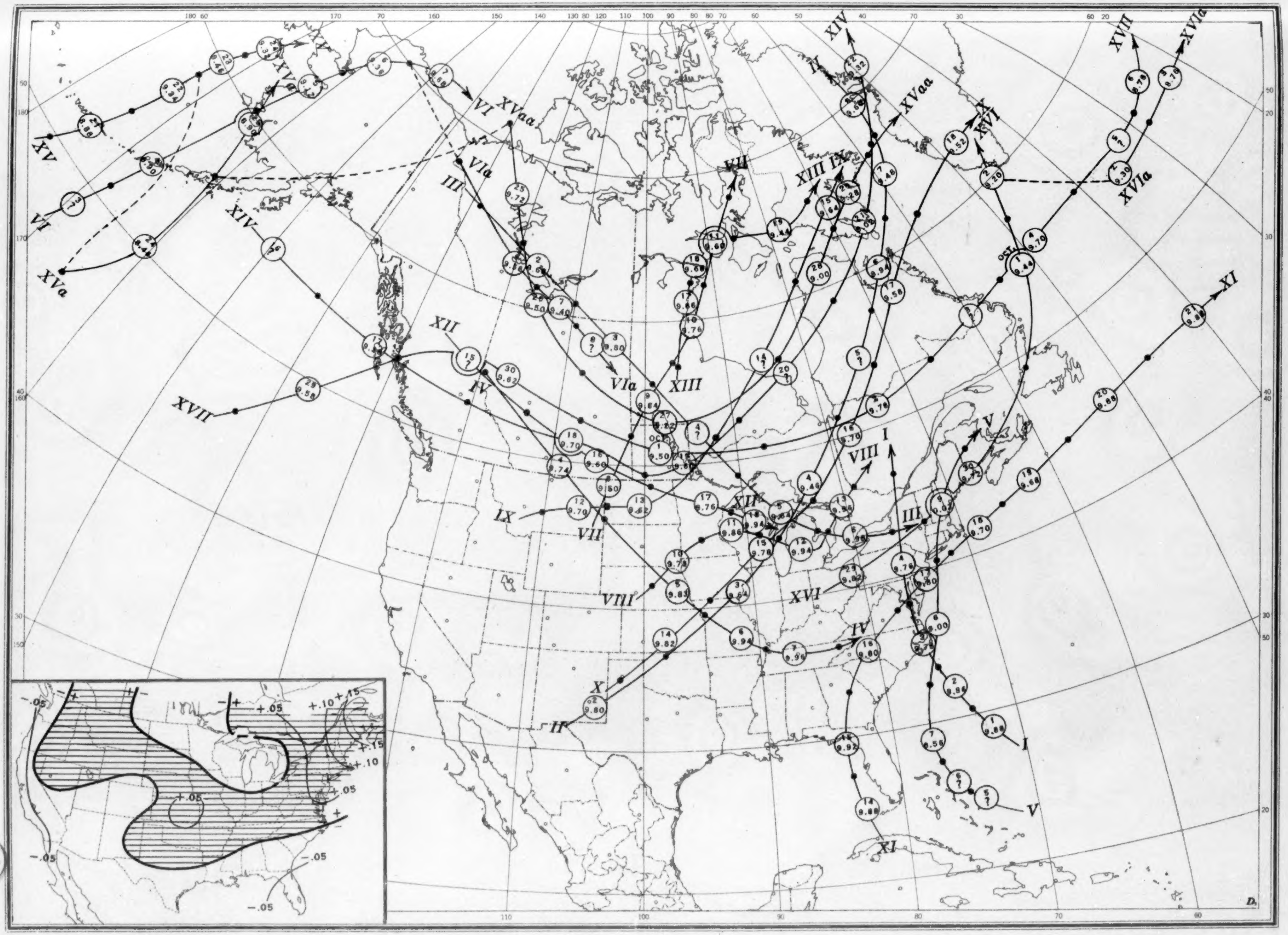


Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, September 1934. (Inset) Change in Mean Pressure from Preceding Month

Circle indicates position of anticyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of anticyclone at 8 p. m. (75th meridian time).

Chart III. Tracks of Centers of Cyclones, September 1934. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by G. E. Dunn)



Circle indicates position of cyclone at 8 a. m. (75th meridian time), with barometric reading. Dot indicates position of cyclone at 8 p. m. (75th meridian time).

Chart IV. Percentage of Clear Sky Between Sunrise and Sunset, September 1934

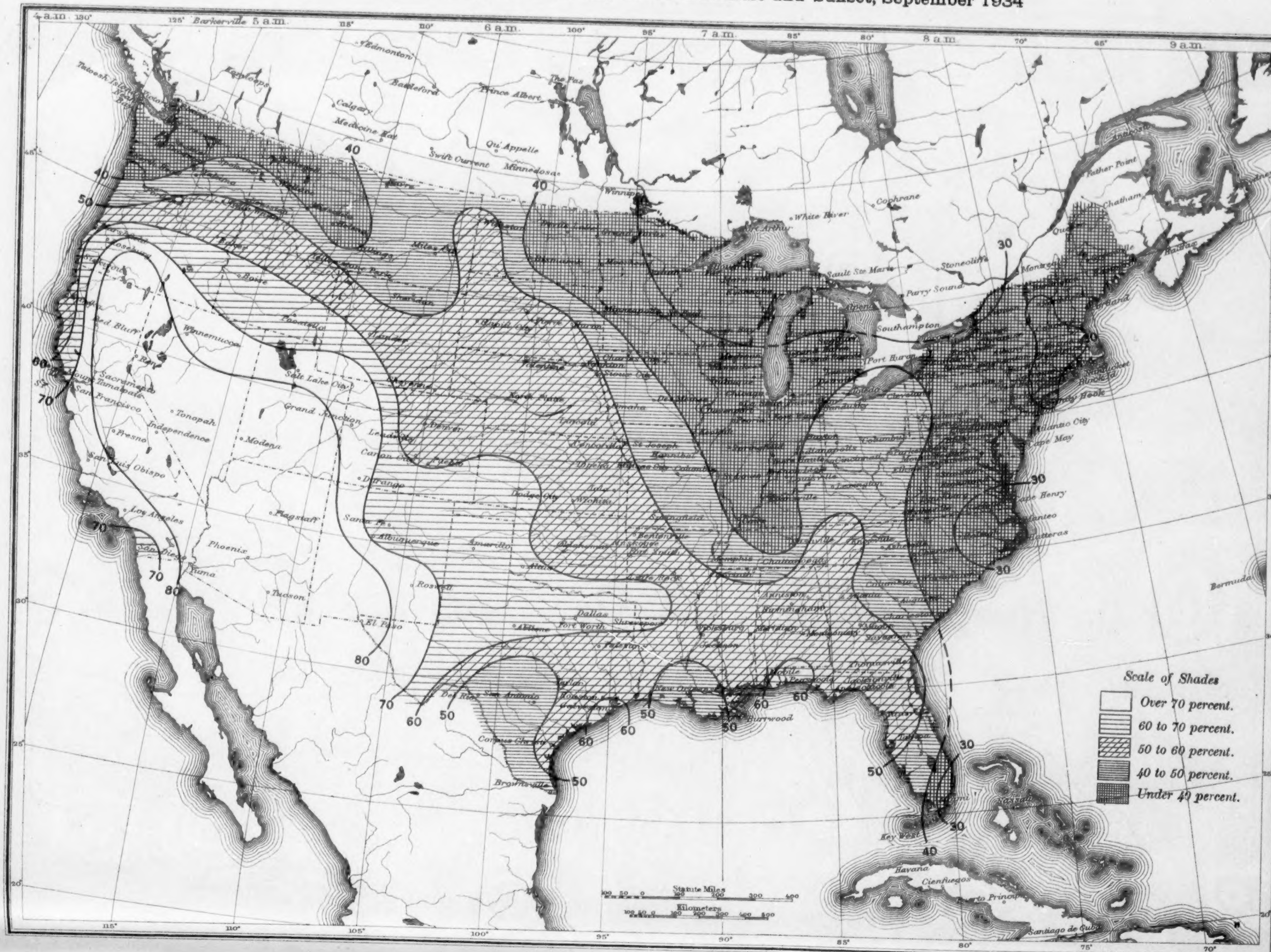


Chart V. Total Precipitation, Inches, September 1934. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, September 1934. (Inset) Departure of Precipitation from Normal

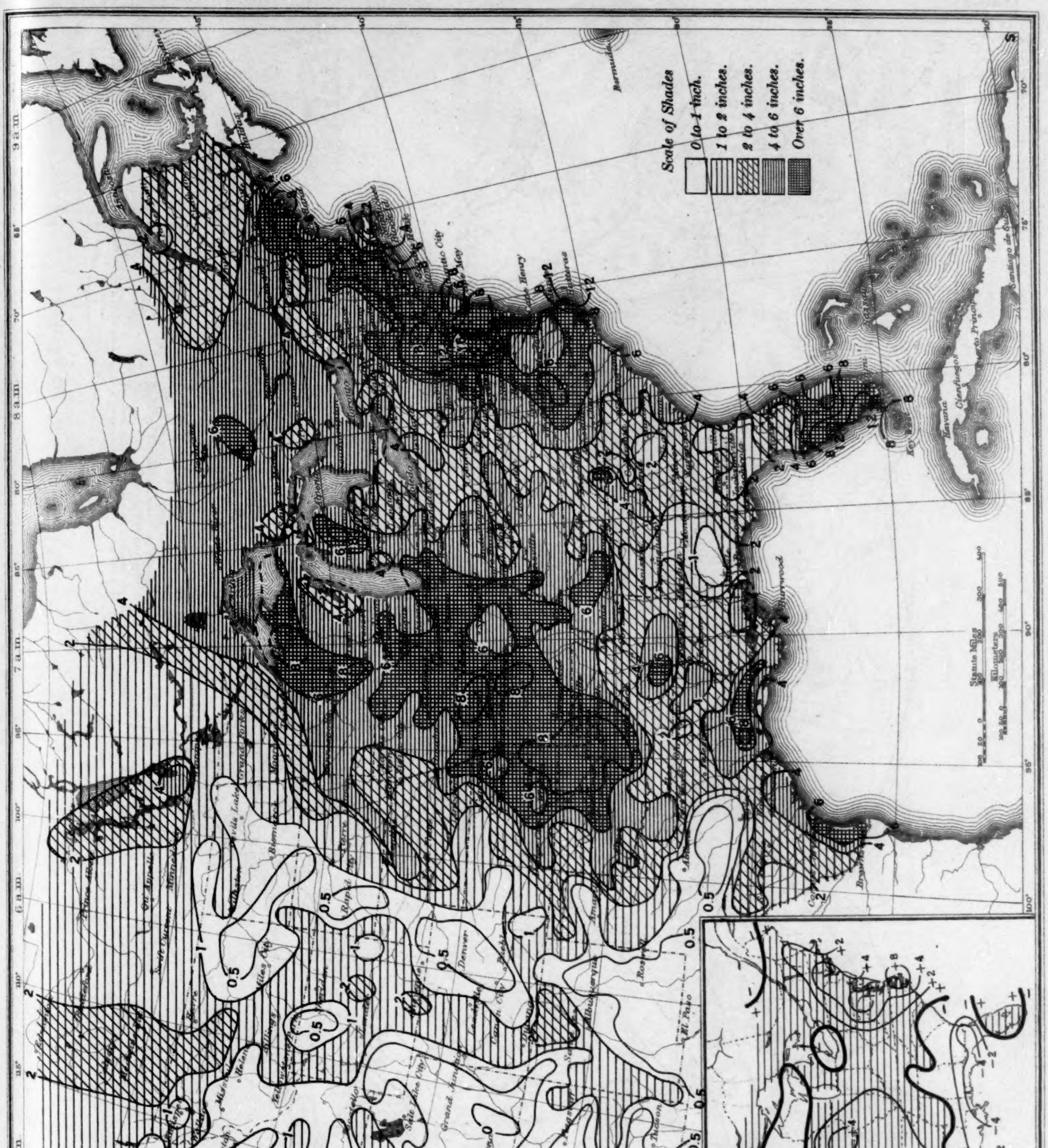


Chart VI. Isobars at Sea Level and Isotherms at Surface; Prevailing Winds, September 1934

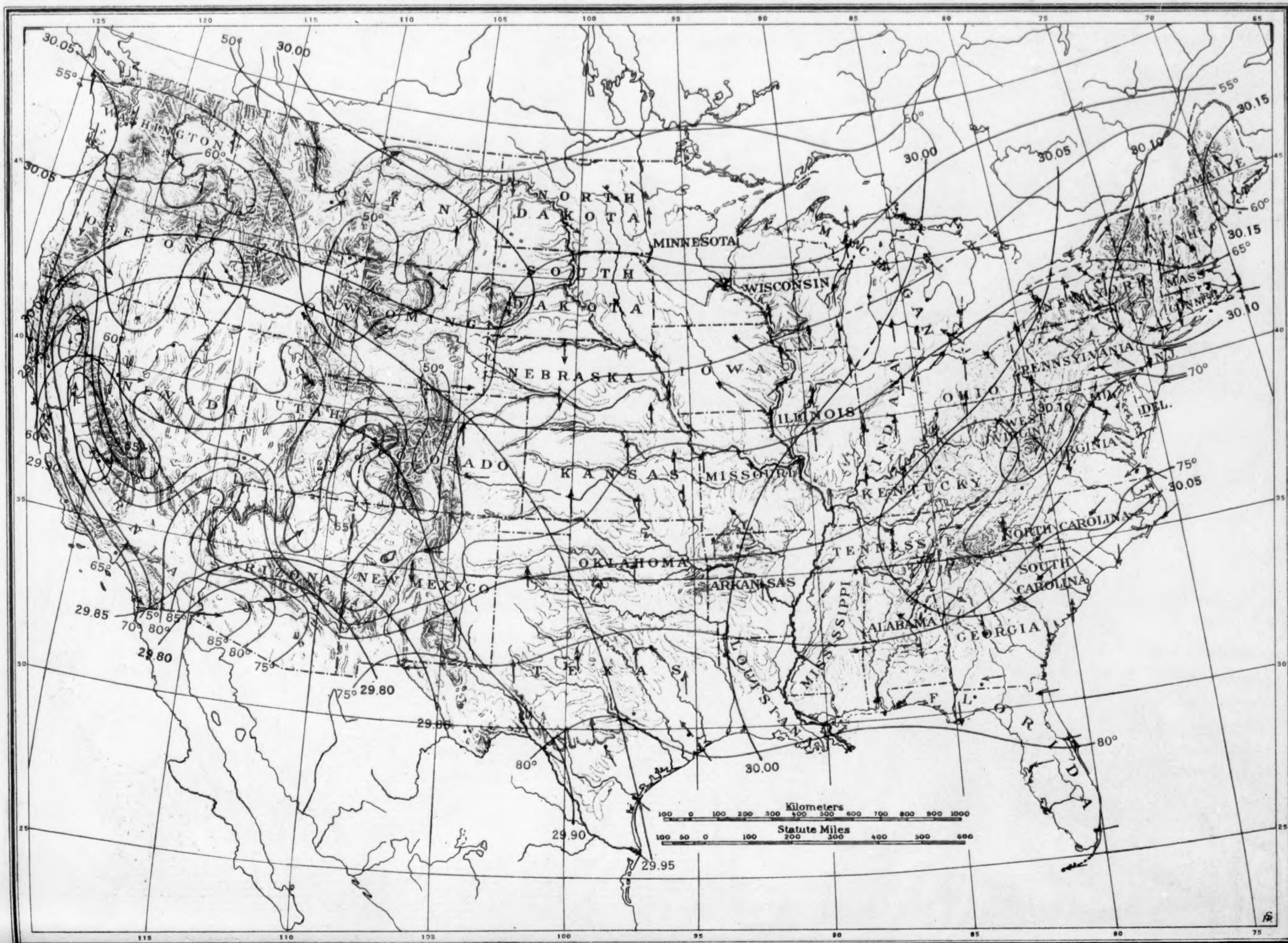


Chart VIII. Weather Map of North Atlantic Ocean, September 7, 1934

Chart VIII. Weather Map of North Atlantic Ocean, September 7, 1934
(Plotted from the Weather Bureau Northern Hemisphere Chart)

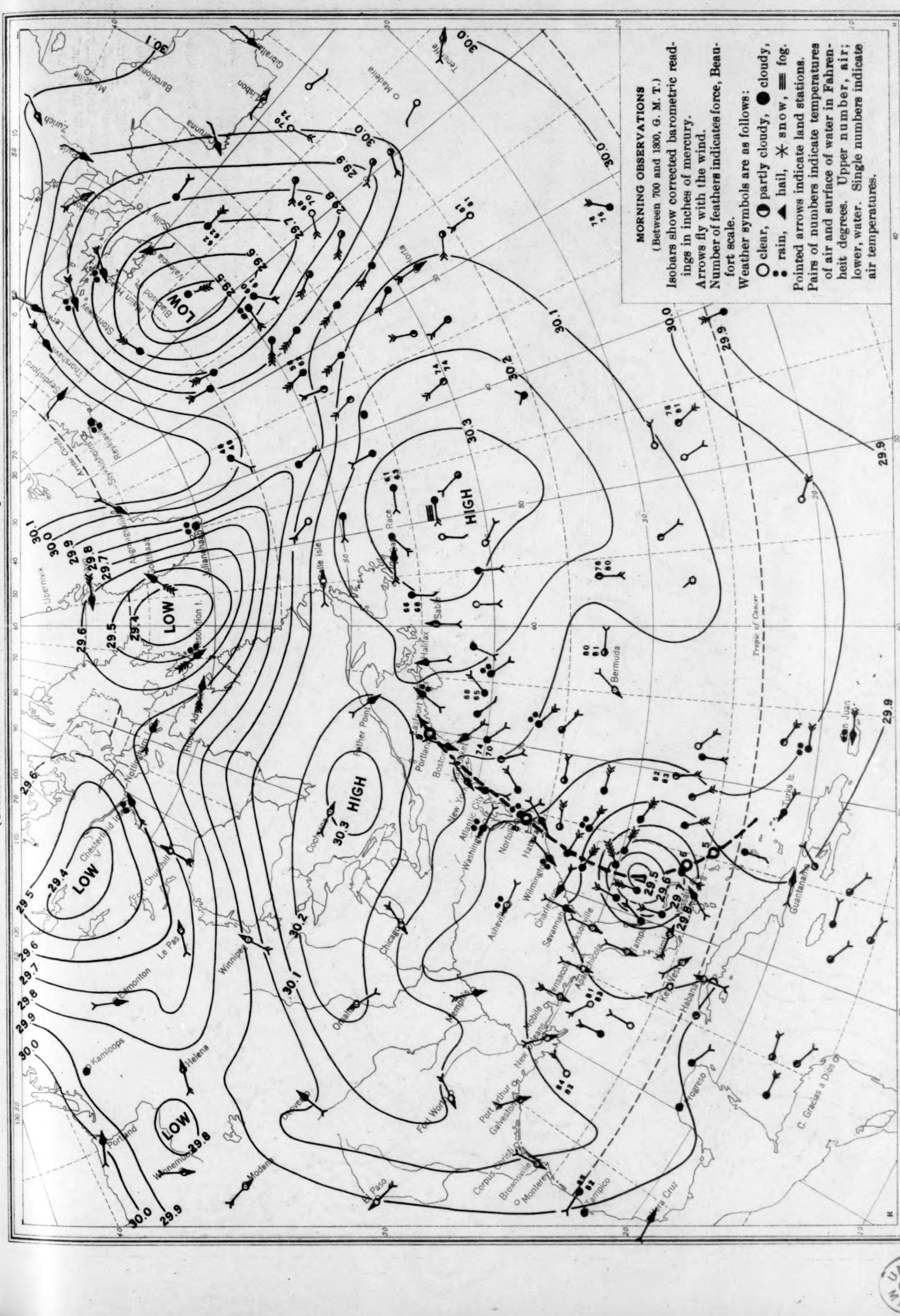
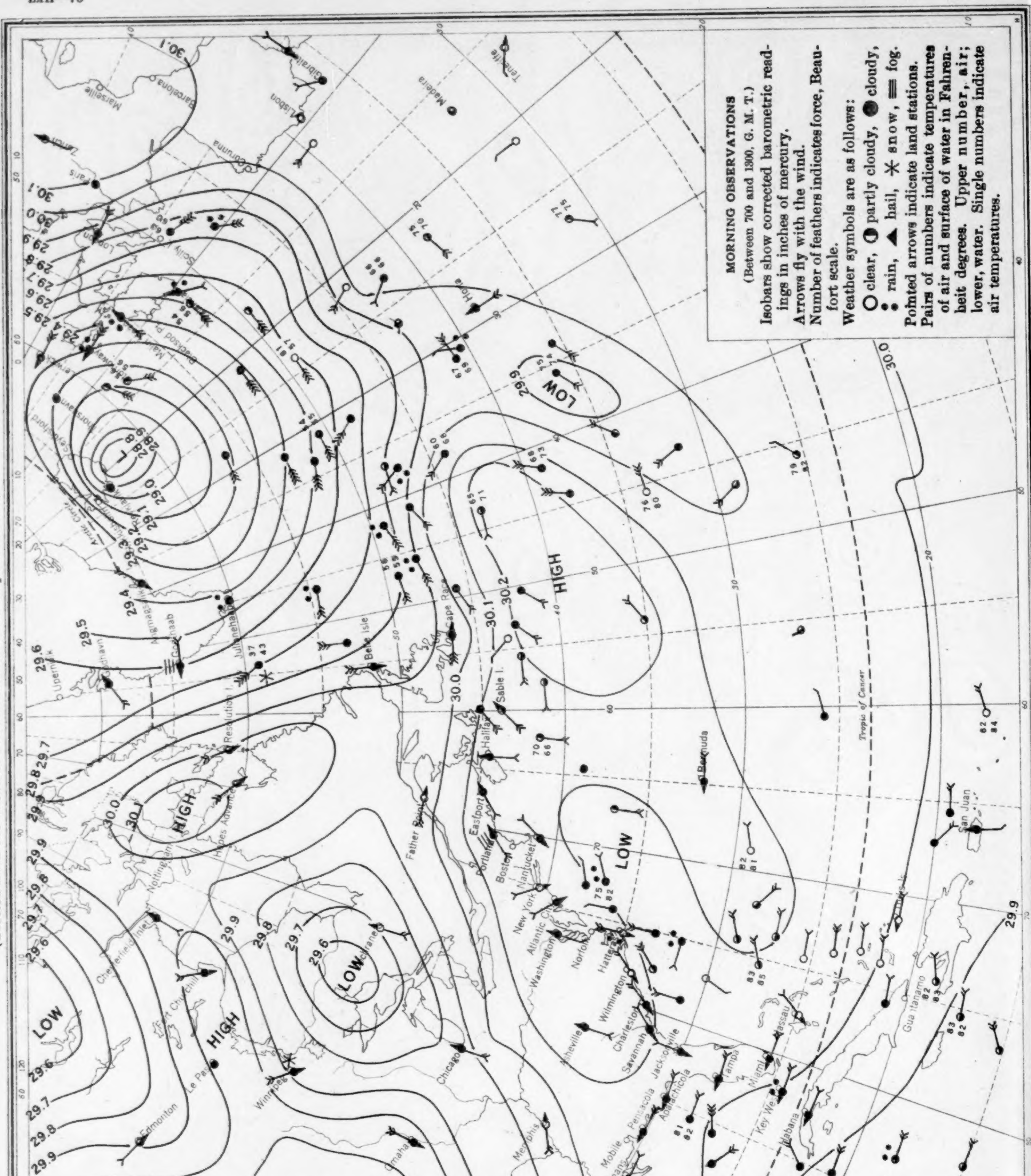
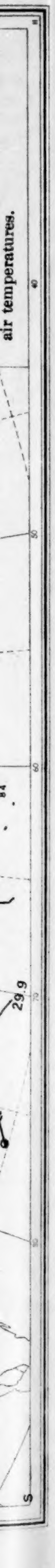


Chart IX. Weather Map of North Atlantic Ocean, September 26, 1934

(Plotted from the Weather Bureau Northern Hemisphere Chart)




air temperatures.
29.9